

Longleaf Pine Silviculture

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ECOLOGICAL LAND CLASSIFICATION OF LONGLEAF PINE ECOSYSTEMS IN THE SOUTHERN LOAM HILLS OF SOUTH ALABAMA

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Abstract—A landscape scale classification of ecosystems was undertaken on the Conecuh National Forest and Solon Dixon Forestry Education Center in south Alabama. Following the USDA Forest Service National Hierarchical Framework of Ecological Units, the three landtype associations in the study area were the Pine Hills, Dougherty Plain, and Wet Pine Flatwoods. The major environmental variables distinguishing the landtype associations were landform index, A horizon depth, B horizon depth, drainage class, A horizon P, percent B horizon clay, and percent B horizon silt. By interrelating vegetation, soils, and landform variables, two to four landtypes were identified in each landtype association along a moisture gradient from mesic to xeric. The diagnostic variables in the Pine Hills were landform index, slope, B horizon depth, B horizon N, A horizon fine sand, and A horizon silt. Dougherty Plain diagnostic variables included depth to mottling, B horizon fine sand, and A horizon Ca. In the Wet Pine Flatwoods, the diagnostic variables were slope, water table presence within 203 cm of the surface, depth to mottling, percent B horizon clay, and drainage class. Diagnostic species also were identified for each landtype.

INTRODUCTION

A key step of natural resource management is the delineation of land units that are similar relative to type, structure, and productivity of vegetation. Ecological Land Classification (ELC) accomplishes this by simultaneously interrelating vegetation, soils, and landform variables (Barnes and others 1982). This reveals diagnostic vegetation, soil, and landform variables that can be used to classify land into its appropriate land unit. Following the USDA Forest Service hierarchical framework of ecological units, the land units are termed Landtype Associations (LTAs) and Landtypes (LTs). LTAs are delineated on the basis of hydrology, geology, and topography, while LTs are delineated primarily on the basis of vegetation, soils, and landform.²

The ELC approach was applied in the uplands of the Southern Loam Hills of south Alabama in order to identify LTAs and LTs. The Southern Loam Hills are part of the longleaf pine (*Pinus palustris*) belt that extends from Virginia to Texas (Wahlenberg 1946). It previously covered 24 million hectares (ha) (Croker 1990) but presently occupies 1.5 million ha (Kelley and Bechtold 1990). Although there have been numerous descriptions of the vegetation and soils of longleaf pine ecosystems (Marks and Harcombe 1981, Pessin 1933, Gilliam and others 1993), few studies have attempted to identify and describe the large scale variation in the structure of the ecosystems.³ Restoration and management of longleaf pine ecosystems are hindered by these deficiencies in information. This research addresses the present deficiencies in information pertaining to the structure of longleaf pine ecosystems in the Southern Loam Hills by (1) delineating ecosystems, (2) determining the soil and landform variables related to the ecosystems, and (3) producing discriminant functions for predicting ecosystems based on soil and landform variables.

METHODS

The study area was the Conecuh National Forest and Solon Dixon Forestry Education Center. This represented an area of approximately 36,450 ha; however, floodplains and bays were excluded from the study. The area is located in the Southern Loam Hills Subsection of the Lower Coastal Plain and Flatwoods Section of the Outer Coastal Plain Mixed Forest Province (McNab and Avers 1994).

One hundred eighteen circular 0.04-ha plots were established throughout the study area. Vegetation, soils, and landform variables were sampled at each plot. Vegetation strata sampled were trees, saplings, seedlings, shrubs and vines, and herbs. The d.b.h. cm was sampled for trees and saplings, while the frequency of seedlings and herbs was determined from four 1 by 10 meter subplots. With the vegetation data, relative importance values were calculated. Soil variables sampled were the depth of the A and B horizons, depth to the argillic horizon, depth to mottling, depth to the water table, Oe and Oi horizon thickness, and drainage class. Soil samples were collected for later analysis that included soil texture determination, total N and C percent, and P, K, Ca, and Mg in parts per million. The landform variables included landform index, terrain shape index (McNab 1991), slope gradient, and aspect.

Using species importance values, land units were determined through a combination of ordination and cluster analysis. The ordination method employed was canonical correspondence analysis (CCA) (ter Braak 1987). CCA utilizes a combination of species importance values and environmental variables to arrange sample units (plots) along axes (Jongman and others 1995). This results in vegetatively similar plots clustering together and dissimilar plots separating. Cluster analysis was performed using TWINSpan (Hill 1979). This program uses species

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² USDA Forest Service. 1993. National hierarchical framework of ecological units. Draft report.

³ Palik, B.J.; Mitchell, R.J.; Kirkman, L.K.; Michener, W.K. 1995. Structure and function of the longleaf pine ecosystem: review and synthesis. Draft report. On file with: Joseph W. Jones Ecological Center, Newton, GA.

importance values to divide the plots into successively smaller clusters of similar vegetation. Ordination was used in conjunction with cluster analysis to avoid subjectivity in delineating land units.

Once land units were delineated, stepwise discriminant analysis was used to determine which environmental variables were related to the vegetation (diagnostic variables) and to create discriminant functions (SAS Institute 1990). The ability of each discriminant function to correctly classify land units was tested with resubstitution and crossvalidation (SAS Institute 1990).

RESULTS

Through ordination and cluster analysis, nine landscape scale LTs were identified in the uplands of the Southern Loam Hills within three LTAs. The LTAs had previously been identified by the USDA Forest Service based on hydrology, geology, and topography.⁴ They are the Pine Hills, Dougherty Plain, and Wet Pine Flatwoods. These LTAs were found to be valid with significant differences in the vegetation, soils, and landform. The diagnostic soil and landform variables ($p \leq 0.10$ level) were A horizon depth, B horizon depth, drainage class, A horizon P, percent B horizon clay, and percent B horizon silt. This combination of variables was significant ($p \leq 0.10$ level). The success rate of classifying the LTAs with discriminant functions and the diagnostic variables was determined by resubstitution (SAS Institute 1990). It resulted in rates of 84, 78, and 88 percent for the Pine Hills, Dougherty Plain, and Wet Pine Flatwoods, respectively.

Pine Hills Landtypes

Within the Pine Hills LTA, three LTs were identified along a gradient from xeric to intermediate. The discriminating landform and soil variables ($p \leq 0.10$ level) were landform

index, slope, B horizon depth, percent B horizon N, percent A horizon fine sand, and percent A horizon silt. The classification success rate with resubstitution was 91, 67, and 92 percent for the xeric, subxeric, and intermediate LTs, respectively.

The vegetation of the intermediate LT was a longleaf pine-shiny blueberry (*Vaccinium myrsinites*)-meadow beauty (*Rhexia alifanus*) type. The overstory was dominated by *Pinus palustris*, while the sapling stratum was sparse. The seedling layer consisted of *V. myrsinites* and *Gaylussacia dumosa*. The herbaceous layer was rich and consisted of *Pityopsis graminifolia*, *R. alifanus*, *Carphephorus odoratissimus*, and *Pteridium aquilinum* (table 1).

The vegetation of the subxeric LT was a longleaf pine-post oak (*Quercus stellata*)-winged sumac (*Rhus copallina*) type. The tree stratum was similar to that of xeric sites with *Pinus palustris*, *Comus florida*, and *Q. falcata*. The sapling layer was sparse with no dominant species. The seedling stratum consisted of *Q. falcata*, *Rhus copallina*, *Q. stellata*, *V. myrsinites*, *V. corymbosum*, *V. arboreum*, and *Q. hemisphaerica*. The most common herbaceous species were *Smilax glauca* and *Pteridium aquilinum* (table 1).

The xeric LT vegetation was a longleaf pine-bluejack oak (*Q. incana*)-morning glory (*Ipomoea* sp.) type. The overstory was dominated by *Pinus palustris*, *Q. falcata*, and *Comus florida*. *Q. laevis* was not common and was only found on xeric sites. The sapling layer was sparse with *Q. margaretta* the only common species. The seedling stratum was a mixture of *Q. incana*, *Q. margaretta*, *Q. falcata*, *Q. hemisphaerica*, and *V. arboreum*. The herbaceous layer included *Ipomoea* spp., *Stylisma humistrata*, *Smilax glauca*, *Pteridium aquilinum*, and *Carphephorus odoratissimus* (table 1).

Dougherty Plain Landtypes

Within the Dougherty Plain LTA, two LTs were identified along a gradient from xeric to intermediate. The unique species of the Dougherty Plain LTA include *Aristida stricta*

Table 1—Vegetative types, diagnostic species, and diagnostic variables for the Pine Hills Landtypes

Landtype	Intermediate	Subxeric	Xeric
Vegetative type	Longleaf pine-shiny blueberry-meadow-beauty	Longleaf pine-post oak-winged sumac	Longleaf pine-bluejack oak-morning glory
Diagnostic species	<i>Vaccinium myrsinites</i> <i>Gaylussacia dumosa</i> <i>Pteridium aquilinum</i> <i>Pityopsis graminifolia</i> <i>Rhexia alifanus</i>	<i>Quercus stellata</i> <i>Rhus copallina</i> <i>Quercus falcata</i> <i>Vaccinium myrsinites</i> <i>Pteridium aquilinum</i>	<i>Quercus margaretta</i> <i>Cornus florida</i> <i>Quercus incana</i> <i>Stylisma humistrata</i> <i>Ipomoea</i> spp.
Diagnostic variables:	Landform index, slope, B horizon depth, percent A horizon silt, percent A horizon fine sand, and percent B horizon nitrogen		

and *Q. virginiana*. The diagnostic physical variables ($p \leq 0.10$ level) were depth to mottling, percent B horizon fine sand, and A horizon Ca. The overall classification success rate based on resubstitution and cross-validation was 91 and 86 percent for the xeric and intermediate LTs, respectively.

The vegetation of the intermediate LT was a longleaf pine-highbush blueberry (*V. corymbosum*)-pinweed (*Lechea minor*) type. The overstory was dominated by *Pinus palustris*, while the sapling stratum was sparse. Species common in the seedling layer were *Q. falcata*, *V. arboreum*, *Diospyros virginiana*, *V. corymbosum*, *G. dumosa*, and *Comus florida*. The herbaceous stratum was dominated by *Lechea minor*, *Crotolaria purshii*, *Oxalis comiculata*, *Danthonia sericea*, *Smilax glauca*, *Silphium compositum*, and *Elephantopus tomentosus* (table 2).

The vegetation of the xeric LT was a longleaf pine-common persimmon (*Diospyros virginiana*)-elephant's foot (*E. tomentosus*) type. The overstory was dominated by *Pinus palustris*. The sapling layer was sparse, while the seedlings were numerous. Common seedlings included *Q. incana*, *Q. virginiana*, *Q. falcata*, *Diospyros virginiana*, *R. copallina*, *V. corymbosum*, *V. arboreum*, *Comus florida*, and *G. dumosa*. Common herbaceous species were *E. tomentosus*, *Gelsemium sempervirens*, *Vitis rotundifolia*, *Stylosanthes biflora*, *Aristida stricta*, and *Hibiscus aculeatus* (table 2).

Wet Pine Flatwoods Landtypes

The Wet Pine Flatwoods had vegetation and soil characteristics unique in the study area. The most distinctive characteristic was the presence of the water table within 203 cm of the surface in 69 percent of the plots. Vegetation unique to this LTA included *Aristida stricta*, *Clethra alnifolia*, *Drosera brevifolia*, and *Pinus elliotii*.

In the Wet Pine Flatwoods, four LTs were identified along an environmental gradient from xeric to bogs. The significant environmental variables ($p < 0.10$ level) were slope, water table presence within 203 cm of the surface, depth to mottling, percent B horizon clay, and drainage class. The overall success rates of classification ($p \leq 0.10$ level) for both resubstitution and cross-validation were 80,

100, 83, and 78 percent for xeric, intermediate, mesic, and bog LTs, respectively.

The vegetation of the bogs was a slash pine-longleaf pine-sweet pepperbush (*Clethra alnifolia*) type. The overstory dominance was equally shared by *Pinus palustris* and *P. elliotii*. The sapling layer was sparse with no dominant species. The seedling stratum was dominated by *Clethra alnifolia*, *V. myrsinites*, *V. stamineum*, and *Gaylussacia mosieri*. The common herbaceous species included *Rhexia alifanus*, *Drosera brevifolia*, *Smilax glauca*, *Carphephorus odoratissimus*, and *Aristida stricta* (table 3).

The vegetation of mesic LT was a longleaf pine-slash pine (*P. elliotii*)-deerberry type. The overstory was dominated by *Pinus elliotii* and *P. palustris*. No saplings were common, and the seedling layer was dominated by a few species. The species included *V. stamineum*, *Acer rubrum*, *Aronia arbutifolia*, and *Gaylussacia mosieri*. Common herbaceous species were *Aristida stricta*, *Carphephorus odoratissimus*, *Arundinaria gigantea*, *Rhexia alifanus*, *Smilax glauca*, and *Drosera brevifolia* (table 3).

The vegetation of the intermediate LT was a longleaf pine-deerberry (*V. stamineum*)-hibiscus (*Hibiscus aculeatus*) type. The overstory was dominated by *Pinus palustris* and *Pinus elliotii*. The sapling stratum was sparse, while the seedling stratum was rich. Seedling species included *V. stamineum*, *Symplocos tinctoria*, *Q. hemisphaerica*, *V. myrsinites*, *Clethra alnifolia*, and *Prunus umbellata*. Among the common herbaceous species were *H. aculeatus*, *Aristida stricta*, *Smilax glauca*, *L. minor*, and *Parthenocissus quinquefolia* (table 3).

On xeric sites, the vegetation was a longleaf pine-common persimmon-wild sarsaparilla (*Smilax glauca*) type, with the overstory dominated by *Pinus palustris*. The sapling layer was sparse, but the seedling layer was rich. Common seedlings included *Clethra alnifolia*, *Rhus copallina*, *Q. falcata*, *Diospyros virginiana*, *Symplocos tinctoria*, *V. myrsinites*, and *Q. hemisphaerica*. Common herbaceous species included *H. aculeatus*, *Smilax glauca*, and *Aristida stricta* (table 3).

Table 2—Vegetative types, diagnostic species, and diagnostic variables for the Dougherty Plain Landtypes

Landtype	Intermediate	Xeric
Vegetative type	Longleaf pine-highbush blueberry-pinweed	Longleaf pine-common persimmon-elephant's foot
Diagnostic species	<i>Vaccinium corymbosum</i> <i>Lechea minor</i> <i>Danthonia sericea</i> <i>Oxalis comiculata</i> <i>Crotolaria purshii</i>	<i>Diospyros virginiana</i> <i>Gelsemium sempervirens</i> <i>Quercus virginiana</i> <i>Q. incana</i> <i>Elephantopus tomentosus</i>
Diagnostic variables:	Depth to mottling, percent B horizon fine, fine sand, and A horizon Ca	

Table 3—Vegetative types, diagnostic species, and diagnostic variables for the Pine Hills Landtypes and Wet Pine Flatwoods Landtypes

Landtype	Bogs	Mesic	Intermediate	Xeric
Vegetative type	Slash pine-longleaf pine-sweet pepperbush	Slash pine-longleaf pine-deerberry	Longleaf pine-deerberry-hibiscus	Longleaf pine-common persimmon-wild sarsaparilla
Diagnostic species	<i>Pinus elliotii</i> <i>Clethra alnifolia</i> <i>Gaylussacia mosieri</i> <i>Rhexia alifanus</i> <i>Drosera brevifolia</i>	<i>Pinus elliotii</i> <i>Vaccinium stamineum</i> <i>Acer rubrum</i> <i>Drosera brevifolia</i> <i>Arundinaria gigantea</i>	<i>Vaccinium stamineum</i> <i>Symplocos tinctoria</i> <i>Hibiscus aculeatus</i> <i>Lechea minor</i> <i>Prunus umbellata</i>	<i>Diospyros virginiana</i> <i>Rhus copallina</i> <i>Quercus falcata</i> <i>Hibiscus aculeatus</i> <i>Smilax glauca</i>

Diagnostic variables: Slope, depth to mottling, B horizon clay, variables presence of water table, and drainage class

DISCUSSION

Within each LTA, two to four LTs were identified along an environmental gradient from xeric to mesic. The discriminant functions derived through the ELC process will aid in the recognition of ecological site units within the Southern Loam Hills. Due to the integrated nature of ELC, it will not only improve productivity predictions, but it also has implications for wildlife and endangered species management, regeneration techniques, harvesting, pest damage susceptibility, and successional pathways. As forest lands require more intensive and innovative management techniques, ELC can provide the detailed information necessary for making appropriate decisions. It is hoped that this ecological classification will provide a framework suitable for the management activities and potential restoration efforts of the USDA Forest Service. The information provided by ELC can be integrated into a Geographic Information System (GIS) to further improve natural resource management.

During the summer of 1996, an additional 180 plots were sampled. With these data, the seral vegetation of the LTs will be identified, and portions of the Conecuh National Forest will be mapped through GIS. These analyses are currently in progress.

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APPENDIX

Scientific names^a and authorities:

Acer rubrum L.
Aristida stricta Michx.
Aronia arbutifolia (L.) Ell.
Arundinaria gigantea (Walt.) Muhl.
Carphephorus odoratissimus (Gmel.) Herb.
Clethra alnifolia L.
Cornus florida L.
Crotolaria purshii DC.
Danthonia sericea Nutt.
Drosera brevifolia Pursh
Elephantopus tomentosus L.
Diospyros virginiana L.
Gaylussacia dumosa (Andrz.) T. & G.
G. mosieri Small
Gelsemium sempervirens (L.) Ait. F.
Hibiscus aculeatus
Ipomea spp. L.
Lechea minor L.
Oxalis comiculata L.
Parthenocissus quinquefolia (L.) Planch.
Pinus elliotii Engelm.
P. palustris Mill.
Pityopsis graminifolia (Michx.) Nuff.
Prunus umbellata Ell.
Pteridium aquilinum (L.) Kuhn
Quercus falcata Michx.
Q. hemisphaerica Bartr.
Q. incana Bartr.
Q. laevis Walt.
Q. margaretta Ashe
Q. stellata, Wang.
Q. virginiana Mill.
Rhexia alifanus Walt.
Rhus copallina L.
Silphium compositum Michx.
Smilax glauca Walt.
Stylisma humistrata (Walt.) Chapm.
Stylosanthes biflora (L.) BSP
Symplocos Victoria L.
Vaccinium arboreum Marsh.
V. corymbosum Ait.
V. myrsinites Lam.
V. stamineum L.
Vitis rotundifolia Michx.

^a Nomenclature follows Clewell (1985) and Radford and others (1968).

PLANT COMMUNITIES IN SELECTED LONGLEAF PINE LANDSCAPES ON THE CATAHOULA RANGER DISTRICT, KISATCHIE NATIONAL FOREST, LOUISIANA

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Abstract—In Grant Parish, Louisiana, increases in overstory basal area, canopy cover, and development of understory woody plants reduced productivity of herbaceous plants in longleaf pine (*Pinus palustris* Mill.) stands that were managed with fire. Still, the herbaceous plant community can reestablish itself on properly managed upland longleaf pine sites in the West Gulf Region. Management efforts were considered most successful where pinehill bluestem [*Schizachyrium scoparium* var. *divergens* (Hack.) Gould] is the dominant herbaceous plant. The lack of oak (*Quercus* spp.) and hickory (*Carya* spp.) regeneration on more mesic sites was worrisome. Use of nested subplots was the best method for monitoring herbaceous vegetation.

INTRODUCTION

Fire was essential for the formation of many southern pine ecosystems. Today, failure to use prescribed fire in upland longleaf pine landscapes results in encroachment by hardwood trees and shrubs and the loss of native pine and herbaceous vegetation. For example, in Alabama over 90 percent of the green biomass on the forest floor of young unburned longleaf pine stands is woody vegetation, while in periodically burned stands, less than 50 percent of the green biomass on the forest floor is woody vegetation (Boyer 1995). This woody vegetation can form a closed midstory that reduces species richness and productivity of the herbaceous plant community (unpublished field notes).

Only about 5 percent of the pine forest lands in Louisiana is publicly owned (Vissage and others 1992). Given the limited acreage, it makes sense to manage these lands for rare and endangered species, old growth characteristics, and other things that may be beyond the management capability of private landowners. As public lands are managed for these other attributes, monitoring becomes necessary for both legal and practical reasons.

In January 1993, the Kisatchie National Forest and the Southern Research Station began monitoring the effects of operational-scale burning in longleaf pine forests on overstory and midstory trees and shrubs and understory vegetation. In addition, research studies on the Catahoula Ranger District (RD) have provided useful information about the effects of fire. We are reporting on the fire effects from operational-scale burns done on two Ecosystem Management Project (EMP) sites and will compare those results to research findings.

SITES

All sites are on the Catahoula RD, Kisatchie National Forest, Grant Parish, LA. Elevations of the sites range from 53 to 76 meters (m). These sites are within the historical range of the upland longleaf pine forest type of the humid temperate, subtropical, outer coastal plain mixed forest, and are located in the coastal plains and flatwoods

Western Gulf Ecoregion of the Southern United States (McNab and Avers 1994). The mean January and July temperatures are 10 and 28 °C, respectively (Louisiana Office of State Climatology 1995). Yearly precipitation averages 143 centimeters (cm) and growing-season precipitation averages 82 cm. The growing season is more than 200 days long; it usually begins before or during early March and ends because of dry weather in October.

The two research sites are as follows:

RES1: The site is a slightly sloping upland of Metcalf (Aquic Glossudal@ and Cadeville (Albaquic Hapludal@ very fine sandy loams. An existing stand [7,450 stems per hectare (ha)] of 6-year-old loblolly pine (*Pinus taeda* L.) was clearcut and the debris burned before 0.093-ha study plots were established. For the next 11 years, woody vegetation was controlled by biennial burning and by severing of all woody and blackberry (*Rubus* spp.) stems over 1 m tall. Over the next decade, a pasture of native woody and herbaceous plants became reestablished. We are using data from plots burned biennially in early May from 1982 through 1992.

RES2: The stand is a 17-ha longleaf pine shelterwood with reserves on a gently rolling upland of Ruston and Smithdale (Typic Paleudults) sandy loam soils. The shelterwood was established in 1968 when the initial preparatory cut left a residual basal area of 8.4 m² per ha. A seed-tree cut in 1975 left 6.9 m² per ha of basal area. The seed trees have been reserved for the management of red-cockaded woodpecker (*Picoides borealis*) habitat. The stand has been prescribed burned 11 times from 1969 through May 1993. Burns were during all seasons of the year.

The two EMP sites are as follows:

EMPL: The stand is a 188-ha longleaf pine forest on a Ruston, Smithdale, and Malbis (Plinthic Paleudult) sandy loam and loamy sand gently rolling upland. The two most recent prescribed burns were in 1990 and

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February 1993. Backing and striphead fires were employed.

EMP2: The stand is a 99-ha longleaf pine forest on a Ruston and Smithdale sandy loam and loamy sand gently rolling upland. The three most recent prescribed burns were in 1990, July 1993, and May 1995. Backing and flank fires were employed.

PROCEDURES

On RES1, total current-year herbaceous production was determined in February 1994 by clipping the aboveground foliage on 12 systematically located 0.22-m² subplots located within each 0.04-ha plot. Dry matter production (oven-dried at 80 °C for at least 24 hours) was determined after the samples were subdivided into six taxa: pinehill bluestem; other bluestems—mostly broomsedge (*Andropogon virginicus* L.), Elliott's bluestem (*A. elliotii* Chapm.), big bluestem (*A. gerardii* Vitm.), and slender bluestem (*S. tenerum* Nees); longleaf uniola [*Chasmanthium sessiliflorum* (Poir) Yates]; other grasses—mostly switchgrass (*Panicum virgatum* L.), yellow indiagrass [*Sorghastrum avenaceum* (Michx.) Nash], low panicums (*Dichanthelium* spp), lovegrass (*Eragrostis* spp.), and threeawn (*Aristida* spp.); grasslikes—mostly nutrush (*Scleria* spp.), sedge (*Carex* spp.), flatsedge (*Cyperus* spp.), spikesedge (*Eleocharis* spp.), rush (*Juncus* spp.), and beakrush (*Rhynchospora* spp.); and forbs. In March 1994, all woody, blackberry, and vine stems were counted and heights and crown spreads estimated on five systematically located 40-m² subplots.

On RES2, EMP1, and EMP2, 0.04-ha plots were established for measuring heights and d.b.h. of the overstory and midstory trees. There were 16 plots on the uplands in RES2 and 10 plots on both EMP1 and EMP2. Inventories were made in May 1996 on EMP1 and EMP2 and in July 1996 on RES2.

Within each 0.04-ha plot, five 4-m² subplots were systematically established for identifying and counting

understory woody stems, blackberry stems, and vines and for measuring heights and crown cover of the woody and blackberry stems. This brush was inventoried in April 1995 on EMP2, in August 1995 on EMP1, and in August 1996 on RES2.

On RES2, five lines of 20 0.22-m² subplots were placed at equal distances apart across the site for inventorying herbaceous plant species. The lines were spaced 80 m apart and the subplots were spaced 16 m apart in each line. Only 86 of the 100 subplots fell on the upland soils. The remaining 14 subplots were in the Guyton (Typic Glossaqual) drainages and were not used. All herbaceous plants with root collars in the subplots were inventoried in July 1996. After the inventories, the herbaceous plants in the subplots were clipped to groundline to determine dry matter production.

Twelve 100-point transects were permanently located on both EMP1 and EMP2. These were used to inventory herbaceous plants. Each transect was 30 m long and readings were made every 30 cm. Readings were made through a circular loop 2 cm in diameter. The loop was held about 30 cm from the eye and 60 cm above the ground. All herbaceous plants seen through the loop were recorded. Readings were made in April 1995 on EMP2 and in August 1995 on EMP1. In September 1995, current-year herbaceous vegetation was clipped to groundline within seven 0.22-m² subplots adjacent to each transect to determine dry matter production on both EMP1 and EMP2.

RESULTS AND DISCUSSION

Overstory and Midstory Vegetation

On RES2, EMP1, and EMP2 total stocking and basal area ranged from 54 to 279 stems per ha and 8.0 to 24.4 m² per ha (table 1). Canopy cover was too sparse to measure accurately on RES2 but averaged 67 percent on EMP1 and EMP2. Longleaf pine dominated the overstory on all sites

Table 1—Number and basal area of overstory and midstory trees and shrubs and the percentage of the stand in longleaf pine (*Pinus palustris* Mill.)

Stands ^a	Number of stems/ha		Basal area (m ² /ha)			Total canopy cover
	Total	Longleaf pine	Total	Longleaf pine	Longleaf pine	
----- <i>Percent</i> -----						
RES2— shelterwood with reserves	54	48	8.01	7.67	96	- ^b
EMPI— forest	279	124	24.36	19.85	81	77
EMP2— forest	210	153	24.40	21.89	90	57

^a RES1 had no overstory or midstory vegetation.

^b No data for this sparse overstory.

and made up from 81 to 96 percent of the total basal area. These three stands were classed as pure longleaf pine based on basal area (Ford-Robertson 1971).

More species of overstory and midstory trees and shrubs occurred on EMP1 and EMP2 than on RES2. Species other than longleaf pine represented a greater portion of the stand basal area on EMP1 and EMP2 than on RES2 (table 1).

EMP1 had nine common overstory and midstory species: longleaf pine, mockernut hickory [*Carya tomentosa* (Poir) Nutt.], flowering dogwood (*Cornus florida* L.), sweetgum (*Liquidambar styraciflua* L.), loblolly pine, southern red oak (*Q. falcata* Michx.), post oak (*Q. stellata* Wangerh.), black oak (*Q. velutina* Lam.), and sassafras [*Sassafras albidum* (Nutt.) Nees]. The common species on EMP2 were longleaf pine, mockernut hickory, blackgum (*Nyssa sylvatica* Marsh.), loblolly pine, southern red oak, blackjack oak (*Q. marilandica* Muenchh.), post oak, and black oak. On RES2, the common species were longleaf pine, sweetgum, southern red oak, and post oak.

Common Understory Woody Plants

Excluding blackberry, there were 16 tree, 15 shrub, and 15 vine species on EMP1, and 12 tree, 15 shrub, and 12 vine species on EMP2. Excluding pine seedlings, there were 60,100 tree, shrub, and blackberry stems per ha on EMP1, and 74,100 per ha on EMP2 (table 2). Height of this brush averaged 0.8 m on EMP1 and 0.5 m on EMP2. Vines numbered 86,600 per ha on EMP2 and 71,100 per ha on EMP1.

Excluding blackberry, there were six tree, nine shrub, and five vine species on RES2 and three tree, six shrub, and three vine species on RES1. Excluding pine seedlings, there were 24,500 tree, shrub, and blackberry stems per ha on RES2, and 9,700 per ha on RES1 (table 2). Vines numbered 27,800 per ha on RES2 and 4,900 per ha on RES1.

The number of longleaf pine seedlings in the grass stage ranged from none on RES1 to 260,000 per ha 21 months after burning on EMP2. The number of loblolly pine seedlings ranged from 150 per ha 30 months after burning on RES2 to 9,300 per ha on EMP2. However, these small pine seedlings failed to develop because of the presence of overstory trees on RES2, EMP1, and EMP2 or because of continual cutting on RES1. While each successive burn reduced the number of pine seedlings, the population recovered between burns. This cycle should continue until there is either a natural disturbance or a change in management.

Tree species common in the understory were red maple (*Acer rubrum* L.), flowering dogwood, sweetgum, blackgum, black cherry (*Prunus serotina* Ehrh.), southern red oak, post oak, and sassafras, although the stocking and average height of these species varied among sites (table 2). Red maple was not in the overstory on RES2, EMP1, and EMP2. However, red maple is susceptible to fire, and it may be being curtailed by burning on these upland sites (Haywood 1995).

Other hardwoods are also susceptible to fire (Chen and others 1975). Prescribed burning kills back the tops of hardwood stems but the root system is affected less (Silker 1961). This results in an increase in stem numbers, but the regrowth is smaller. However, continual burning—especially on an annual or biennial basis—eventually reduces the numbers and vigor of woody stems (Lotti 1956, Chen and others 1975).

On both EMP1 and EMP2, the overstory species not well represented in the understory were mockernut hickory, black oak, and blackjack oak. On RES2, the overstory species not well represented in the understory was post oak. Thus, it appears that oaks and hickories are not completely regenerating.

Shrub taxa in the understory included American beautyberry (*Callicarpa americana* L.), southern bayberry or waxmyrtle (*Myrica cerifera* L.), shining sumac (*Rhus copalina* L.), blackberry, tree sparkleberry (*Vaccinium arboreum* Marsh.), and other blueberries (*Vaccinium* spp.) (table 2). Common vine taxa in the understory were rattanvine [*Berchemia scandens* (Hill) K. Koch], Carolina jessamine [*Gelsemium sempervirens* (L.) Ait. f.], Japanese honeysuckle (*Lonicera japonica* Thunb.), dewberry (*Rubus trivialis* Michx.), greenbrier (*Smilax* spp.), poison oak [*Toxicodendron toxicarium* (Salisb.) Gillis], and grape (*Vitis* spp.). Vines were most plentiful on EMP1 and EMP2, and numbers of vines varied from 4,900 per ha on RES1 to 86,600 per ha on EMP2.

Common Herbaceous Plants

On all four sites, the most well-distributed plants were pinehill bluestem, low panicums, swamp sunflower (*Helianthus angustifolius* L.), grassleaf goldaster [*Heterotheca graminifolia* (Michx.) Shinners], and bracken fern [*Pteridium aquilinum* var. *pseudocaudatum* (Clute) Heller].

The total frequency of occurrence for all herbaceous vegetation was 30 percent on EMP1 and 74 percent on EMP2. The total current-year herbaceous production was 452 kilograms (kg) per ha on EMP1 and 753 kg per ha on EMP2.

On RES2, the total frequency of occurrence for all herbaceous vegetation was 805 percent. This high frequency of occurrence resulted partly from use of 0.22-m² subplots, whereas a 2-cm loop was used on EMP1 and EMP2. However, total current-year herbaceous production was 1,859 kg per ha on RES2. So, the plant cover was more abundant where overstory stocking was less, however the measurements were taken. No data on frequency of occurrence were collected on RES1, but total current-year herbaceous production was 3,204 kg per ha. Of this total, 79 percent was in grasses, 6 percent in grasslikes, and 15 percent in forbs.

Common Grasses

There were 19, 26, and 18 taxa of grasses commonly found on RES2, EMP1, and EMP2, respectively. The

Table 2—Number of stems per hectare and average height (ht) in meters of the principal understory trees, shrubs, and blackberry, excluding longleaf and loblolly pine, and number of principal vines per hectare; cover types are pasture of native plants (RES1), longleaf shelterwood with reserves (RES2), and longleaf forests (EMP1 and EMP2)

Taxa	Stands							
	RES1		RES2		EMP1		EMP2	
	Stems	Ht	Stems	Ht	Stems	Ht	Stems	Ht
Trees								
<i>Acer rubrum</i> red maple	— ^a	—	1,077	1.8	346	1.3	2,323	0.8
<i>Cornus florida</i> flowering dogwood	—	—	—	—	2,768	0.7	9,933	0.6
<i>Liquidambar styraciflua</i> sweetgum	1,235	0.8	2,308	1.2	1,433	1.6	148	0.3
<i>Nyssa sylvatica</i> blackgum	—	—	—	—	297	0.6	2,372	1.1
<i>Prunus serotina</i> black cherry	—	—	—	—	939	2.1	1,631	0.9
<i>Quercus falcata</i> southern red oak	2,140	0.4	4,769	0.8	2,125	0.7	1,631	0.6
<i>Q. stellata</i> post oak	—	—	—	—	198	0.3	8,896	0.5
<i>Sassafras albidum</i> sassafras	—	—	769	0.3	2,817	0.6	4,893	0.8
Shrubs and blackberry								
<i>Callicarpa americana</i> American beautyberry	—	—	308	0.6	5,387	1.4	3,805	1.2
<i>Myrica cerifera</i> southern bayberry	3,292	0.8	154	1.1	9,489	0.7	7,611	0.3
<i>Rhus copallina</i> shining sumac	165	0.8	3,077	0.6	3,212	0.9	6,820	0.5
<i>Rubus</i> spp. blackberry	329	0.3	4,154	0.3	19,719	0.9	9,390	0.4
<i>Vaccinium arboreum</i> tree sparkleberry	1,152	0.4	2,615	0.3	544	0.7	1,631	0.6
<i>V. virgatum</i> , <i>elliottii</i> , and <i>stamineum</i> other blueberries	—	—	3,230	0.4	6,870	0.6	6,374	0.2
All trees and shrubs ^b	9,712	0.6	24,462	0.6	60,146	0.8	74,130	0.5
Vines ^c								
<i>Berchemia scandens</i> rattanvine	—		—		10,724		395	
<i>Gelsemium sempervirens</i> Carolina jessamine	4,115		2,923		15,963		10,625	
<i>Lonicera japonica</i> Japanese honeysuckle	—		—		297		17,989	
<i>Rubus trivialis</i> dewberry	—		11,538		9,340		26,588	
<i>Smilax bona-nox</i> , <i>glauca</i> <i>rotundifolia</i> , and <i>smallii</i> greenbrier	741		3,539		6,030		13,690	
<i>Toxicodendron toxicarium</i> poison oak	—		9,846		14,282		9,093	
<i>Vitis rotundifolia</i> and <i>aestivalis</i> grape	—		—		5,634		5,337	
All vines ^b	4,856		27,846		71,117		86,632	

^a Taxon was not present.

^b Number of stems for all trees and shrubs may also include numbers for taxa not reported in the table.

^c Vine heights were not measured.

grasses that occurred most frequently were pinehill bluestem and low panicums on RES2 and EMP2 and pinehill bluestem and big bluestem on EMP1 (table 3). Spreading panicum (*Panicum anceps* Michx.) was also common on these three sites. On RES1, pinehill bluestem made up 58 percent, other bluestems 14 percent, and all of the other grasses 7 percent of the total current-year herbaceous production.

Other Herbaceous Plants

The grasslike plant most common on all uplands was nutrush. There were 22, 9, and 22 species or genera of

composites on RES2, EMP1, and EMP2, respectively. The composite most common on these three uplands was grassleaf goldaster. Swamp sunflower was common on RES1, RES2, and EMP2. Both of these species are indicators of well-developed herbaceous plant communities.

Legumes numbered 19, 8, and 14 species or genera on RES2, EMP1, and EMP2, respectively. The frequency of occurrence of the legumes averaged only 2 percent on EMP1 and EMP2, but was 176 percent on RES2. We believe that the method of sampling was a factor in the

Table 3—Grass taxa with frequency of occurrence exceeding either 4 percent on RES2 or 1 percent on EMP1 and EMP2; data on frequency of occurrence were not taken on RES1. Cover types are longleaf shelterwood with reserves (RES2) and longleaf forests (EMP1 and EMP2)

Taxa	Stands		
	RES2 ^a	EMP1	EMP2
	----- Percent -----		
<i>Andropogon gerardii</i> big bluestem	1.16	2.67	0.75
<i>A. subtenuis</i> fineleaf bluestem	4.65	— ^b	—
<i>Aristida purpurascens</i> arrowfeather threeawn	23.26	0.08	1.25
<i>Chasmanthium laxum</i> and <i>C. sessiliflorum</i> spike and longleaf uniola	—	2.25	2.00
<i>Dichanthelium</i> spp. low panicums	79.07	1.50	12.67
<i>Eragrostis elliotti</i> and <i>E. spectabilis</i> Elliott and purple lovegrasses	4.65	0.25	0.08
<i>Gymnopogon ambiguus</i> bearded skeletongrass	18.60	0.17	1.42
<i>Muhlenbergia expansa</i> cutover muhly	4.65	0.08	—
<i>Panicum anceps</i> spreading panicum	3.49	1.83	1.00
<i>P. virgatum</i> switchgrass	2.33	1.67	—
<i>Schizachyrium scoparium</i> var. <i>divergens</i> pinehill bluestem	95.35	7.58	8.08
<i>S. tenerum</i> slender bluestem	12.79	—	—
<i>Sporobolus junceus</i> pineywoods dropseed	4.65	0.17	—
All grasses ^c	270.94	21.40	30.82

^a The frequencies of occurrence on RES2 are high partly because the sampling area was a 0.22-m² subplot rather than the 2-cm-diameter loop used on EMP1 and EMP2.

^b Taxon was not present.

^c Frequency of occurrence for all grasses may include frequencies for taxa not reported in table.

difference in legume frequency among sites. On RES2, the legumes that occurred most frequently were showy partridgepea (*Cassia fasciculata* Michx.), littleleaf tickclover [*Desmodium ciliare* (Muhl.) DC.], erect milkpea [*Galactia erecta* (Walt.) Vail], catclaw sensitivebrier (*Schrankia uncinata* Willd.), pencilflower [*Stylosanthes biflora* (L.) BSP.], and Virginia tephrosia [*Tephrosia virginiana* (L.) Pers.].

These findings suggest that it was better to use 0.22-m² subplots than the transect method when inventorying herbaceous plant species. Future work should use a nested subplot technique as recommended by the North Carolina Vegetation Survey.²

The other forbs numbered 26, 10, and 18 species or genera on RES2, EMP 1, and EMP2, respectively. Texas dutchmanspipe (*Aristolochia reticulata* Nutt.) occurred most frequently on RES2, narrowleaf mountainmint (*Pycnanthemum tenuifolium* Schrad.) occurred most frequently on EMP1, and flowering spurge (*Euphorbia corollata* L.) occurred most frequently on EMP2. Bracken fern represented 97 percent of the total fern population on RES2, EMP1, and EMP2.

Effects of the Overstory on Herbaceous Vegetation

The amount of current-year herbaceous production on each site was partly associated with overstory and midstory basal area, canopy cover, and number and size of understory trees and shrubs. EMP1 had the greatest canopy cover, the tallest understory vegetation, and the least current-year herbaceous production. RES1 had no overstory, the fewest understory woody stems, and the greatest herbaceous production.

Continual prescribed burning can be used to reduce understory woody vegetation beneath forest canopies over a number of years, and this may increase herbage production (Lotti 1956, Silker 1961, Chen and others 1975). However, as a pine canopy closes, shading by the overstory and competition for water and nutrients still limit herbaceous production no matter how effectively fire is used (Grelen 1976). Therefore, development of a herbaceous plant community may have to be judged by plant diversity rather than by herbaceous productivity on forest sites. To this end, indicator plants can be used as barometers of the health of herbaceous plant communities.

If overstory competition and understory brush are controlled, these upland longleaf pine sites can support rich

and productive herbaceous plant communities dominated by pinehill bluestem. Also, these results suggest that pinehill bluestem could be used as an indicator of management success in establishing and maintaining herbaceous plant communities on upland longleaf pine sites in the West Gulf Coastal Plain. Examples of other species that could be used as indicators on similar sites are swamp sunflower and grassleaf goldaster.

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LONG-TERM CHANGES IN FLOWERING AND CONE PRODUCTION BY LONGLEAF PINE

William D. Boyer¹

Abstract—Cone production by longleaf pine has been followed for up to 30 years in regeneration areas at five to nine coastal plain sites from North Carolina to Louisiana. A rapid increase in the size and frequency of cone crops has occurred since 1986 following 20 years of relative stability. Cone production for the last 10 years averaged 36 cones per tree versus 14 cones per tree for the preceding 20 years. This change was evident at most sites, including the Escambia Experimental Forest where longleaf pollen shed has been recorded since 1957 and counts of female flowers in regeneration areas since 1970. Although pollen production was cyclic, no long-term change was evident. The recent increase in cone production seems due to both an increase in flower production and an increase in the fraction of flowers surviving to become mature cones.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) is a poor seed producer compared to other southern pines, and seed crops large enough for adequate natural regeneration are relatively rare. Most information on the size of longleaf pine seed crops in the past is anecdotal. Wahlenberg (1946) noted that good seed crops may occur every 5 to 7 years. Heavy seed crops may occur over much of the longleaf range once in 8 to 10 years (Maki 1952). Longleaf seed years have been characterized by relative terms such as failure, light, medium, heavy, or bumper, but these terms have not been tied to actual numbers such as cones per tree or seeds per acre.

In order to achieve satisfactory natural regeneration, the available seed supply must feed all the many predators with enough left over to establish a satisfactory seedling stand. An average of 360 cones per acre is needed to provide for the first seedling. A minimum of 750 and preferably 1,000 or more cones per acre is usually needed for successful regeneration (Boyer and Peterson 1983). The size of longleaf pine cone crops varies greatly from year to year, and also from place to place (Boyer 1987). This irregularity in seed production by longleaf pine is a major problem for the natural regeneration of this species (Croker and Boyer 1975).

Long-term records of longleaf pine cone production were obtained from natural regeneration trials initiated between 1966 and 1969. The tests included nine coastal plain sites from North Carolina to Louisiana, plus two in the montane longleaf forests of central Alabama. Cone production records from these tests, covering the 20-year period from 1966 through 1985, were reported earlier (Boyer 1987). Cone production records for the following 10 years, through 1995, are included in this report.

METHODS

Cooperative operational tests of longleaf pine natural regeneration were established at 11 sites within the southeastern longleaf pine belt. One test site is the Escambia Experimental Forest, Escambia County, AL. Four sites are on national forests in Louisiana, Mississippi,

Alabama, and Florida. Three sites are on State forests in Florida, South Carolina, and North Carolina. Two sites are on private lands in Alabama and Georgia, and one is on a military reservation in Florida.

At each of 10 sites, two tests were established within stands ranging in size from 16 to 128 acres and averaging 64 acres. One was a test of the two-cut and the other the three-cut shelterwood method of natural regeneration (Croker and Boyer 1975). Several tests of the two-cut method only were established on the Escambia Experimental Forest. All tests were located in maturing stands of longleaf pine nearing a saw log rotation.

Twenty-five sample points were established within each test area. Two seed trees nearest each sample point were marked for annual springtime binocular counts of female flowers and conelets (first- and second-year pistillate strobili) using the method described by Croker (1971). Cones produced by each sample tree the preceding fall were also counted. This count included all the cones on the ground under each sample tree plus a binocular count of the cones remaining in each tree. Sample trees were not replaced when removed by cutting or natural mortality, so their number has declined over the years.

Counts ended in 1974 at three sites, two in the montane longleaf type and one on the coastal plain in Mississippi, when the parent overstory was removed following successful regeneration of both tests at each site. Cone count data from the two montane longleaf sites have been omitted due to exceptionally high cone production there as compared to monitored coastal plain sites. For the 8-year period from 1967 through 1974, the montane sites averaged 6.3 times as many cones per tree as five coastal plain sites with records covering the same period of time.

Counts ended at three additional coastal plain sites following 1978, 1979, and 1987 cone crops. Counts were resumed at these three sites, in new shelterwood stands, beginning in 1991, 1992, and 1994. Five coastal plain sites (one each in South Carolina, Georgia, Florida, Alabama, and Louisiana) have nearly complete cone count records,

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with 142 of 144 year-site cells filled. Eight cells at three sites were filled by estimates derived from springtime counts of enlarging conelets. Years of record at each coastal plain site, for both cone and flower counts, are given in table 1. The years listed for flower counts include only those with follow-up cone counts from the same sample trees.

Annual pollen shed by longleaf pine has been monitored on the Escambia Experimental Forest since 1957, using the method described by Grano (1958).

Annual cone counts on regeneration test sites were made to determine the size of cone crops normally needed for satisfactory natural regeneration, and also the frequency of their occurrence at different locations. Binocular counts of flowers and conelets were made to determine their potential value as predictors of cone crop size and so provide some lead time to prepare for an approaching good cone crop.

RESULTS

Long-Term Cone Production

Records of cone production by longleaf pine on coastal plain sites now cover the 30 years from 1966 through 1995. Average annual cone production for all years of record at each location ranged from 7.3 to 37.8 and averaged 21.2 cones per tree (table 2). These results suggest that longleaf pine cone production may increase with increasing distance from the coast.

Table 1—Coastal plain sites and years of record for flower and cone counts

State and county	Flower counts		Cone counts	
	Started (flower yr)	Years counted	Started (cone yr)	Years counted
NC				
Bladen	1969	7	1968	15
SC				
Chesterfield	1970	23	1969	27
GA				
Decatur	1968	23	1967	29
FL				
Santa Rosa	1968	24	1967	29
Okaloosa	1969	12	1968	22
Leon	1967	7	1966	16
AL				
Escambia	1970	25	1966	30
MS				
Perry	1967	6	1966	9
LA				
Grant	1968	18	1967	27

Table 2—Average annual cone production on coastal plain sites

State	County	Cones/tree (average)
North Carolina	Bladen	18.2
South Carolina	Chesterfield	37.8
Georgia	Decatur	10.9
Florida	Santa Rosa	14.3
	Okaloosa	7.3
	Leon	19.6
Alabama	Escambia	22.4
Mississippi	Perry	14.2
Louisiana	Grant	36.2
Average		21.2

Year-to-year variation in cone production for all sites combined was very high, ranging from a low of less than one cone per tree in 1966 to a high of 65 cones per tree in 1987 (fig. 1). A minimum of 750 cones per acre is usually needed for adequate regeneration. This means cone production must average 30 or more cones per tree given 25 residual seed trees per acre in a shelterwood stand.

Both the size and frequency of monitored longleaf pine cone crops have increased substantially during the last 10 years. Cone production for all sites from 1986 through 1995 averaged 35.6 cones per tree. The average for the preceding 20 years was 14.0 cones per tree. For all sites combined, the frequency of cone crops adequate for regeneration (30 or more cones per tree) has changed from an average of once per 6.7 years before 1986 to once per 1.7 years since. A 5-year moving average for cone production at all sites illustrates the change (fig. 2). An apparent region-wide heavy longleaf cone crop in 1996 could push the 5-year average above 50 cones per tree.

Longleaf Flowering and Cone Production

A good longleaf pine cone crop depends on initiation of a large number of female flowers. Although a good female flower crop always precedes a good cone crop, a good cone crop does not always follow a good female flower crop. Pollen supply is another critical factor and, based on 9 years of observation, cone crop size was also closely related to pollen density in the flower year (Boyer 1974). However, large crops of both female and male (staminate strobili) flowers do not necessarily coincide. Weather conditions that promote production of female flowers in southern pines may not be the most favorable for production of male flowers (Boyer 1981).

Escambia Experimental Forest

The Escambia Experimental Forest is the only site where longleaf pine pollen supply has been monitored over a long period of time. This, along with counts of female flowers, permits some exploration of the role of both in year-to-year variations in cone production.

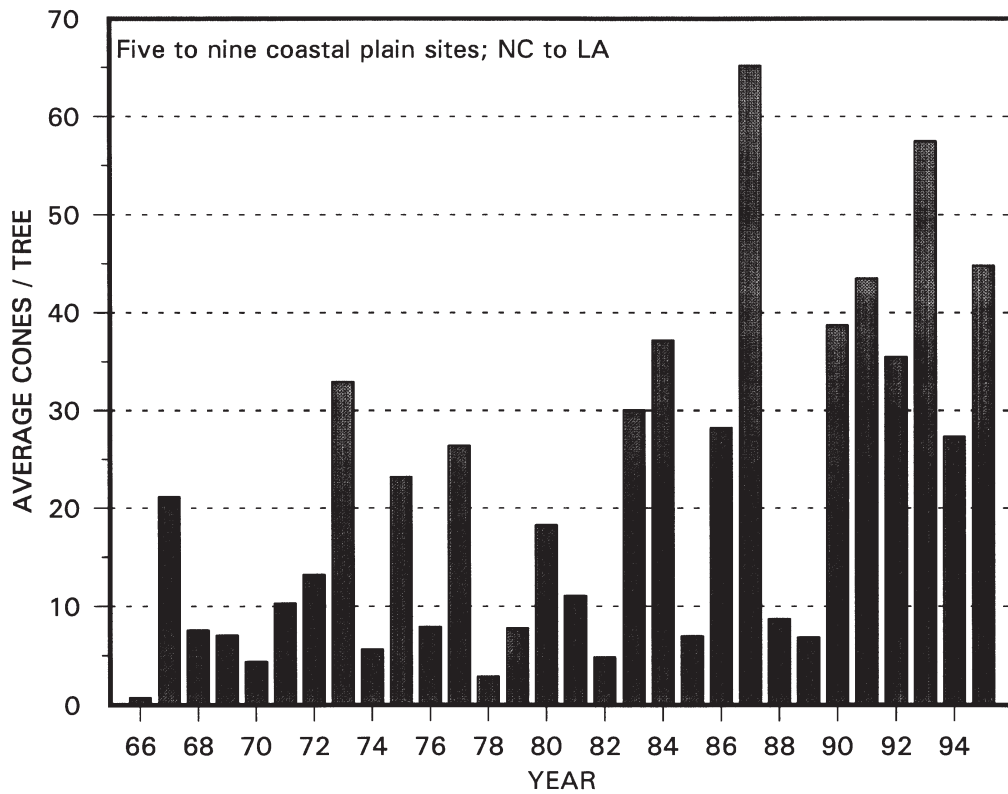


Figure 1—Average annual cone production per tree for all coastal plain sites.

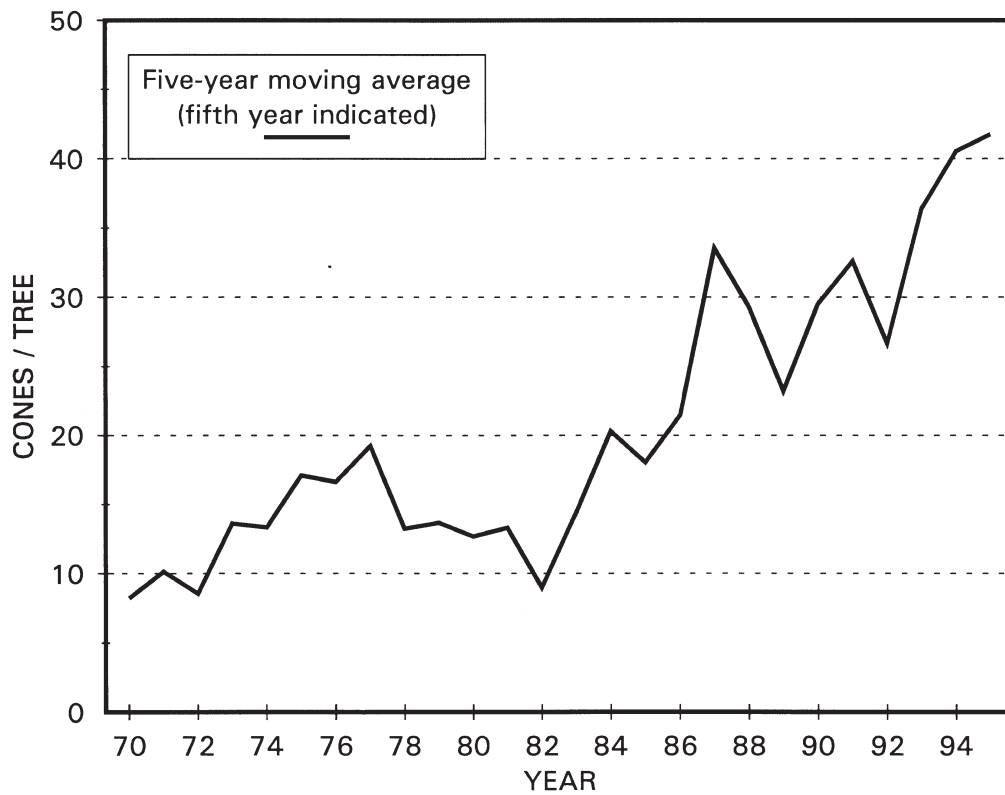


Figure 2—The 5-year moving average of cones per tree for all coastal plain sites.

Cone production by longleaf pine on Escambia Experimental Forest over a 38-year period (1958-95) ranged from a low of 0.2 cones per tree in 1989 to 128.1 cones per tree in 1993, with an overall average of 21.0 cones per tree (fig. 3). The average cone production for the 28 years before 1986 was 16.6 cones per tree. For the 10 years from 1986 through 1995, the average was 33.1 cones per tree, an increase of nearly 100 percent. The increase can be entirely attributed to the heavy cone crops in 1987 and 1993. Omit these 2 years and the average for the remaining 8 becomes 12.4 cones per tree.

Annual pollen supply over 40 years of record (1957-96) has ranged from 0.6 to 24.5 and averaged 7.4 thousand grains per square centimeter (cm²). While cyclic, there is no indication of any long-term increase in pollen supply (fig. 4). Pollen supply averaged 8.4 thousand grains per cm² over the first 20 years, and 6.3 during the last 20 years. In 1957 and 1966, the pollen supply exceeded 20 thousand grains per cm² leading to a higher average for the first 20 years.

Flower counts on sample trees over the 27 years from 1970 through 1996 ranged from 0.2 to 80, and averaged 30.6 per tree (fig. 5). Flower production, both male and female, was less variable from year to year than cone production. Considering only the 25 years with matched flower and cone counts from the same sample trees, the coefficient of variation for annual flower counts was 67.9, and for cone counts 138.0 percent. The coefficient of variation for pollen supply over the same 25-year period was 58.2 percent.

Pollen supply for the 38 years from 1957 through 1994 was related to subsequent cone production (1958-95), although it was not a strong relationship, with a coefficient of determination (r^2) of 0.43. An adequate pollen supply, however, seemed necessary for a good cone crop. Cone production for the 16 years with pollen supply less than 5 thousand grains per cm² averaged 7.0 cones per tree. For the 12 years with pollen supply in excess of 10 thousand grains per cm², cone production averaged 45.1 cones per tree.

Flower counts were more closely related to subsequent cone production, with an r^2 of 0.66. Adding pollen supply increased the r^2 value only to 0.68. There was also a relatively weak relationship between flower counts and pollen supply over 27 years of record, with an r^2 of 0.46.

The large year-to-year variability in pollen supply, flower counts, and cone production on the Escambia Experimental Forest was reduced by 5-year moving averages for all three variables (fig. 6). All values are tied to the year of cone maturity, so that pollen supply and flower counts for the spring of one year are shown under the following year, when these flowers matured into cones. Both the high and especially the low points in the cycles for all three variables generally coincided. After 1986, however, the gap between flower counts and subsequent cone production closed, indicating a rather sharp reduction in the number of flowers per mature cone. Before 1986, there was an average count of 2.1 flowers per cone which declined to 1.0 for the years 1986 through 1995. Flower

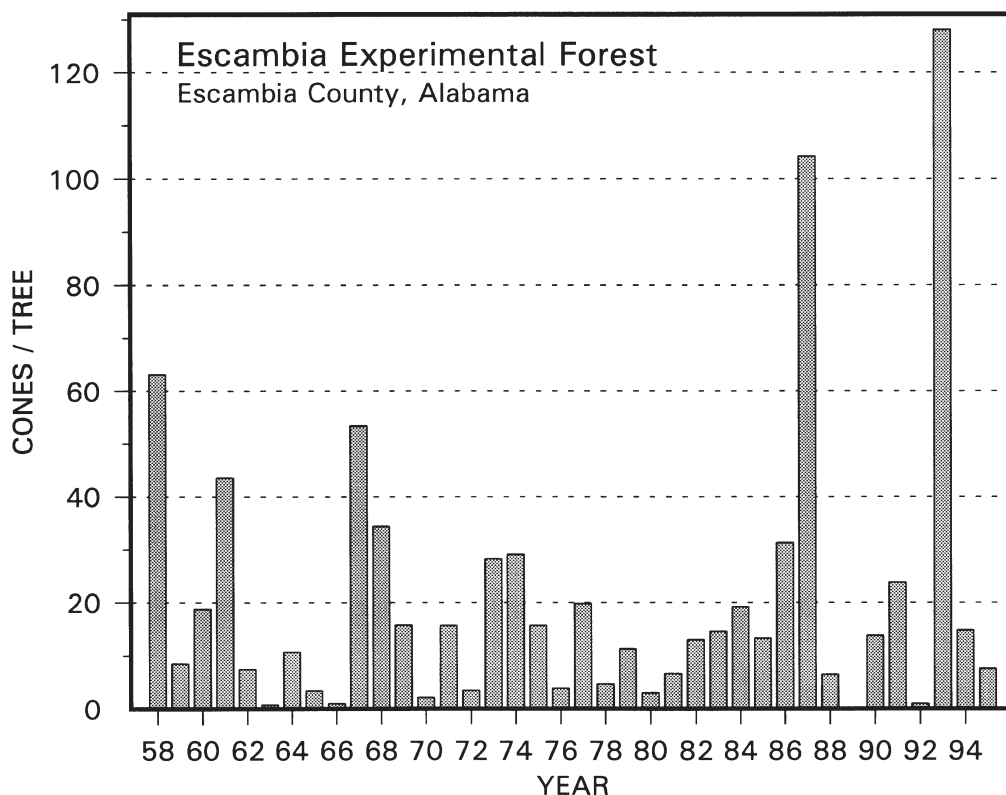


Figure 3—Average annual cone production per tree on the Escambia Experimental Forest.

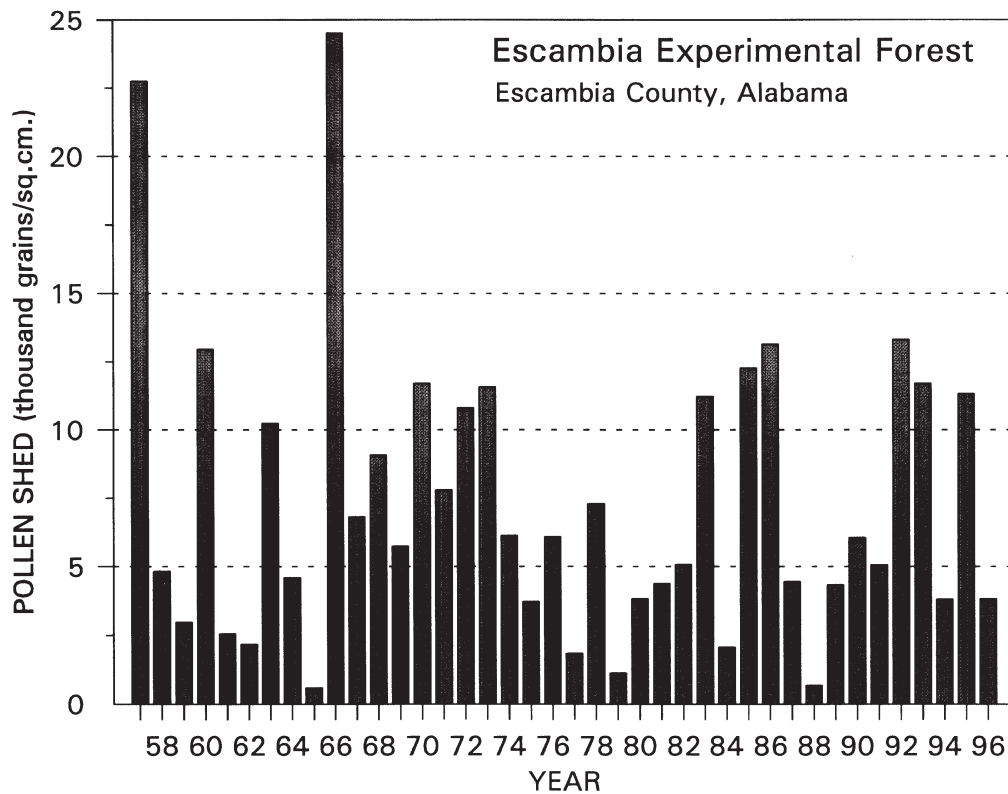


Figure 4—Annual pollen shed by longleaf pine on the Escambia Experimental Forest.

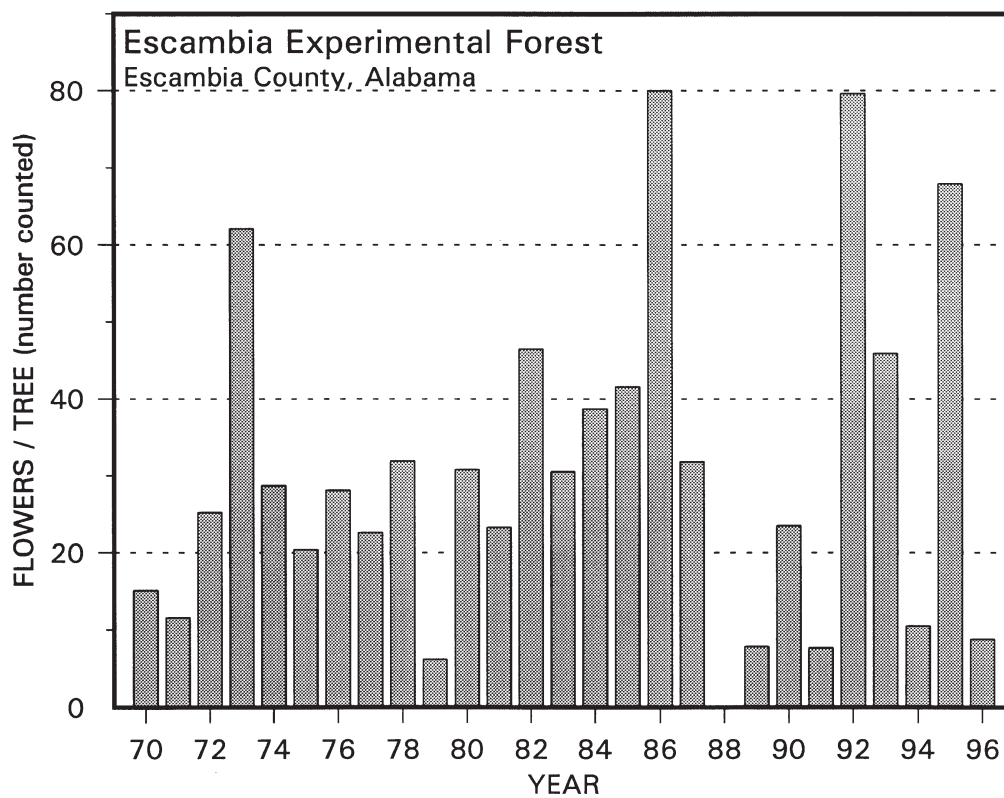


Figure 5—Average annual flower counts per tree on the Escambia Experimental Forest.

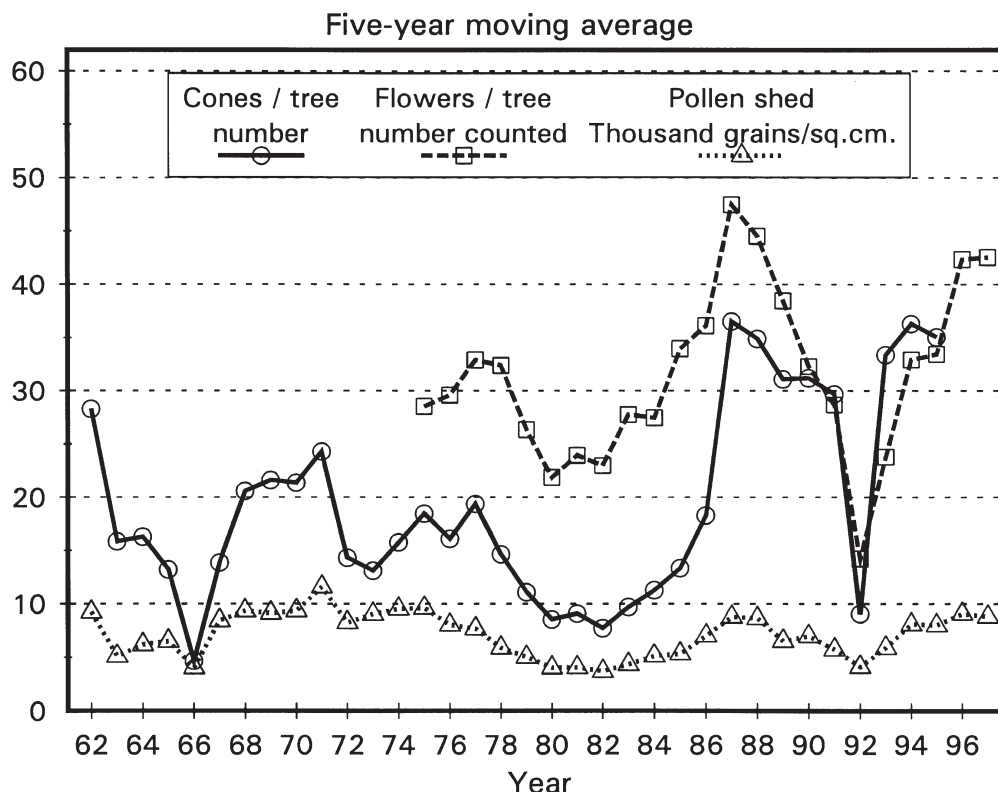


Figure 6—The 5-year moving averages for cone production, flower counts, and pollen supply on the Escambia Experimental Forest.

counts averaged 28.1 per tree before 1986 and 32.9 per tree after, an increase of only 17.1 percent. Cone production for the same trees over the same 25-year period averaged 13.4 per tree before 1986 and 33.1 per tree after, an increase of 147 percent! On the Escambia Experimental Forest, at least, it seems that the large increase in cone production observed after 1985 was due in small part to an increase in production of female flowers, but in larger part to an increase in the number of flowers that survived to become mature cones.

Five Coastal Plain Sites

All five coastal plain sites, including the Escambia Experimental Forest, that were monitored over a relatively long period of time showed increases in flower counts and cone production after 1985 compared to the average for all earlier years. Based on average flower and cone counts per tree for all five sites combined, flower counts increased by 59 percent and cone production by 110 percent (table 3).

The 17.1 percent increase in flower production for the Escambia Experimental Forest was the smallest. Increases in flower counts on the remaining four sites ranged from 40 to 211 percent. Cone production for these same sites increased from 30 to 1,175 percent. At four of the five locations, increases in cone production exceeded the increases in flower counts, suggesting that a larger fraction of flowers survived to become mature cones. The exception was Grant Parish, LA, where an increase of 40

percent in flower counts was greater than the 30 percent increase in cone production.

The average percent increase in flower counts since 1984, for all five coastal plain sites, was 75.1, while the increase in cone production was 337.6. The average for percent change greatly exceeded the increase based on average flower and cone counts for crops in 1986 and later versus the earlier years, since the greatest percentage increases were at locations with the lowest average cone production before 1986. The log of percent increase in cone production at the five sites was strongly related to average size of cone crops before 1986, with an r^2 of 0.88.

Average flower counts and, to a greater extent, cone counts were much less variable among the five coastal plain sites for cone crop years after 1985 than for the earlier years. The coefficient of variation for flower counts declined from 33 to 22 percent, and for cone production from 75 to 25 percent.

DISCUSSION AND CONCLUSIONS

The average size of longleaf pine cone crops on monitored coastal plain sites over the 10 years from 1986 through 1995 was more than double the average size for the preceding 20 years. This change appears due to both an increase in the number of female flowers per sample tree and to an increase in the number of flowers that survived to become mature cones. The relative contribution of these two factors varied among locations.

Table 3—Changes in flower counts and cone production on five coastal plain sites for cone crop years of 1985 and earlier versus 1986 and later

State	County	Flower counts per tree			Cone counts per tree		
		Earlier years	Later years	Change	Earlier years	Later years	Change
		--- Average ---		Percent	--- Average ---		Percent
SC	Chesterfield	34.0	48.5	42.6	33.4	54.2	62.3
GA	Decatur	16.1	50.0	210.6	2.8	35.7	1,175.0
FL	Santa Rosa	21.5	35.6	65.6	7.6	28.4	273.7
AL	Escambia	28.1	32.9	17.1	13.4	33.1	147.0
LA	Grant	43.3	60.5	39.7	39.4	51.2	29.9
	All sites	28.6	45.5	59.1	19.3	40.5	109.8

Longleaf pollen shed, recorded at only one location, was cyclic over a 40-year period with no evident long-term change. An adequate pollen supply along with a good female flower crop appeared necessary requirements for a good cone crop.

Among the five locations with relatively continuous records, the increase in cone production was greatest at the three central Gulf Coast sites, less at the Atlantic Coast and West Gulf sites. Cone production at the Gulf Coast sites was much lower than the other two sites over the first 20 years. The percent increase in cone production was closely related to the average size of pre-1986 cone crops. The site with the largest gain (Decatur, GA) was that with the smallest average pre-1986 cone crop size, and the site with the smallest gain (Grant, LA) was that with the largest average pre-1986 cone crop size. The order is the same for the remaining three sites. Cone production since 1985 at the three Gulf Coast sites is still lower than at the other two sites, but the differences are much smaller.

The sudden and dramatic increase over the last 10 years in the size and frequency of good longleaf pine cone crops certainly suggests some favorable changes in environmental conditions associated with the cone production process. What these changes may be is open to speculation. In view of the regional scale of its occurrence, the most likely cause is some change in climatic conditions. Whether this is a permanent change, or only part of some long-term cycle, remains to be seen, provided flower and cone production records can be continued into the future.

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THE EFFECTS OF PLANTING TOOL ON PLANTING PRODUCTIVITY AND SURVIVAL OF LONGLEAF PINE BARE-ROOT SEEDLINGS

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Abstract—An evaluation was made of the effects of hand planting tool (shovel or dibble) on planting productivity and survival of longleaf pine (*Pinus palustris*) seedlings on two adjacent sites in the upper Coastal Plain of Alabama. In addition, the effects of storage time between lifting and outplanting on survival were measured. Seedlings were planted with both shovels and dibbles on each of two sites harvested in 1995. Site A was clearcut, broadcast-burned in December of 1995, and the site prepared with a Savannah 3-in-1 plow. Site B was clearcut and aerially sprayed with a tank mix of 18 ounces of Arsenal (imazapyr) and 25 ounces of Garlon (triclopyr) per acre in October of 1995. A broadcast burn was performed in December 1995 and the site bedded with the Savannah 3-in-1 plow later that month. Planting began in January of 1996. On each day, shovels and dibbles were used to plant simultaneously on the site. Seedlings were stored at 55 °F between lifting and planting. Storage time ranged from 0 days (planted on the day of lifting) to 13 days. Planting productivity differences were statistically insignificant, averaging 146.8 seedlings per man per hour with shovels and 141.8 seedlings per man per hour with dibbles. Survival at the end of one year also did not differ between implements on individual sites or overall on both sites. Survival on site A was 85 percent with shovels and 86.25 percent with dibbles. On site B, mean survival was 71.88 percent with shovels and 71.46 percent with dibbles. Overall survival was 78.44 percent with shovels and 78.95 percent with dibbles. Due to study design, statistically linking survival to storage time was impossible, but survival of seedlings planted with shovels 0, 1, 3, 6, 7, 9, 10, and 13 days after lifting averaged 87.5 percent, 82.5 percent, 76.25 percent, 81.25 percent, 62.5 percent, 73.75 percent, 72.5 percent and 65 percent, respectively. Survival of seedlings planted with dibbles on the same dates was 87.5 percent, 85 percent, 66.25 percent, 75 percent, 70 percent, 60 percent, 77.5 percent and 80 percent. One year after planting, 22 percent of shovel-planted seedlings had initiated height growth, as had 23 percent of seedlings planted with dibbles. The incidence of height growth initiation declined as storage time increased up to 7 days of storage.

INTRODUCTION

Although there is little documentation, many foresters believe that longleaf pine bare-root seedlings are best planted by planting machine. Machine planting, however, requires a level of site preparation not necessary for hand planting. Less intensive site preparation can lessen adverse effects on the site and often lowers costs. Hand planting is commonly accomplished in the Southeast with dibbles or planting bars. Other tools occasionally used by planters include hoedads and planting shovels. In this study, planting productivity and seedling survival were compared for dibbles and planting shovels.

STUDY AREA

The Solon Dixon Forestry Education Center is located in the upper Coastal Plain of south-central Alabama approximately 60 miles north of the Gulf Coast. The 5,350-acre teaching and research forest ranges from xeric ridges to forested wetlands, and from bottomland hardwood stands to upland longleaf pine stands. The two sites chosen for this study are adjacent and were occupied by similar, mature, mixed pine/hardwood stands prior to clearcutting in 1995. The soils are loamy sands and moderately well drained. There is a slight slope on each site and both have northeastern aspects. Each was site prepared in 1995 using broadcast fire and a Savannah 3-in-1 plow pulled behind a crawler tractor equipped with a V-blade. Both operations took place in December of that year. In addition, one site (site B) was aerially sprayed with a tank mixture of 18 ounces of

Arsenal (imazapyr) and 25 ounces of Garlon (triclopyr) per acre prior to the fire. The plow incorporated soil, organic matter, and some coarse woody debris into beds spaced approximately 10 to 12 feet apart and standing 1 to 1.5 feet high.

METHODS

Planting

The beds were planted in 6-foot intervals with bare-root longleaf pine seedlings obtained from the E.A. Hauss nursery, operated by the Alabama Forestry Commission and located approximately 70 miles from the Dixon Center. All seedlings used in the study were lifted on January 21, 1996 and stored at 55 °F in a refrigerated cooler until outplanting. Planting began on site A on January 21 with freshly lifted seedlings. Planting was done by staff of the Dixon Center, all experienced hand planters. On each day, half of the crew planted with shovels and half with dibbles. On the next planting day, the implements were exchanged to eliminate differences in planting speed or ability. The shovels were used very much like dibbles, i.e., a planting slit was created rather than a dug hole (Blake and South 1991). At the end of each day, the number of seedlings planted with each implement was recorded, seedlings per man-hour calculated, and the block marked with pin flags to assist in subsequent tracking. The planting continued across the two sites until both were planted. Planting took place on the day the seedlings were lifted and 1, 3, 6, 7, 9, 10, and 13 days after lifting. In each case, daily productivity

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was calculated and the blocks identified by day of planting and implement used.

Subsequent Measurements

One year after planting, the sites were sampled to determine survival by day of planting and implement. In addition, data were collected on the incidence of height growth initiation in each block. Evaluation of differences in height growth incidence and survival between sites and among storage time blocks was complicated because of confounding effects, and no conclusions could be reliably drawn.

RESULTS

Planting Productivity

Productivity (trees per man per hour) varied on a day-to-day basis both by implement and by day (table 1). Mean planting productivity with shovels and dibbles was 146.8 and 141.8 trees per man per hour, respectively. Daily rates ranged from highs of 174 trees per man per hour with the shovel and 175 trees per man per hour with the dibble to lows of 121 trees per man per hour with the shovel and 123 with the dibble. Figure 1 depicts this data graphically.

Seedling Survival

Overall survival with each implement across both sites was remarkably similar. On site A, mean survival after 1 year of seedlings planted with shovels was 85 percent. On the same site, mean 1-year survival of dibble-planted seedlings was 86.25 percent. Survival on site B averaged 71.88 percent for seedlings planted with shovels and

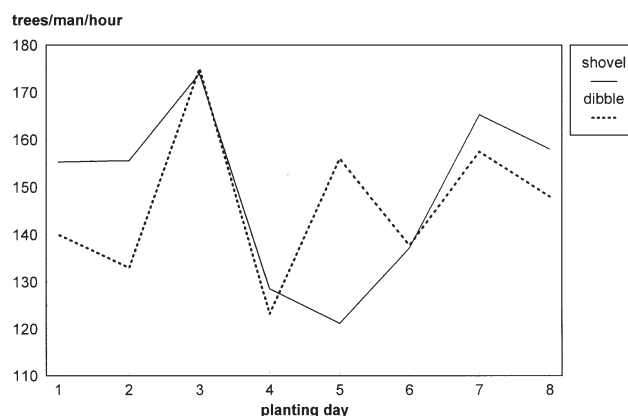


Figure 1—Planting productivity for shovels and dibbles by day.

71.46 percent for seedlings planted with dibbles. Overall survival after 1 year across sites was 78.44 percent for shovel-planted trees and 78.95 for dibble-planted seedlings.

Survival by implement by days of storage is indicated in table 2 and graphically depicted in figure 2. Because the sites were not planted simultaneously and site preparation treatment varied between sites, comparisons cannot safely be made between sites. However, survival on site A was 88.1 percent for seedlings planted on the day of lifting, and 84.4 percent for seedlings planted 1 day later. Seedlings planted on those days with shovels survived at the rates of 88.75 percent and 85 percent, respectively. Those planted on the same days and same site with dibbles survived at

Table 1—Planting productivity

Day	Site	Implement	Trees/man/hour
1	A	Shovel	155.3
	A	Dibble	140.0
2	A	Shovel	155.6
	A	Dibble	133.0
3	B	Shovel	174.0
	B	Dibble	175.0
4	B	Shovel	128.5
	B	Dibble	123.2
5	B	Shovel	121.0
	B	Dibble	156.0
6	B	Shovel	137.2
	B	Dibble	137.7
7	B	Shovel	165.3
	B	Dibble	157.5
8	B	Shovel	158.0
	B	Dibble	148.0
Mean productivity:			
		Shovel	146.8
		Dibble	141.8

Table 2—Year seedling survival by implement and storage time

Site	Days of storage	Implement	Survival rate
			Percent
A	0	Shovel	87.50
	0	Dibble	87.50
A	1	Shovel	82.50
	1	Dibble	85.00
B	3	Shovel	76.25
	3	Dibble	66.25
B	6	Shovel	81.25
	6	Dibble	75.00
B	7	Shovel	62.50
	7	Dibble	70.00
B	9	Shovel	73.75
	9	Dibble	60.00
B	10	Shovel	72.50
	10	Dibble	77.50
B	13	Shovel	65.00
	13	Dibble	80.00

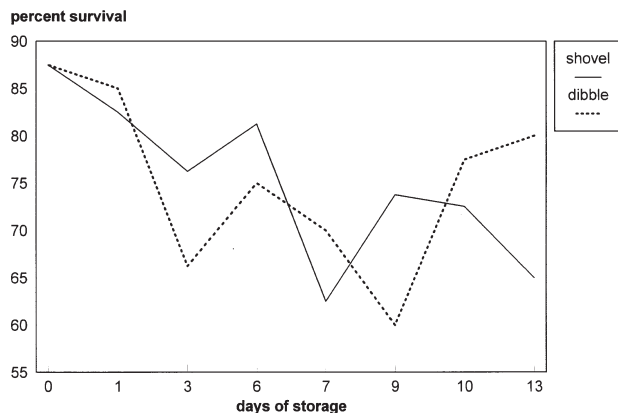


Figure 2—Seedling survival after 1 year by planting implement and storage time.

87.5 percent and 83.75 percent. On site B, seedlings were planted after 3, 6, 7, 9, 10, and 13 days of storage. Overall survival rates for those days was 71.25 percent, 78.1 percent, 66.25 percent, 66.88 percent, 75 percent, and 72.5 percent, respectively. Seedlings planted on site B with shovels had the following survival rates: 3 days storage: 76.25 percent; 6 days: 81.25 percent; 7 days: 62.5 percent; 9 days: 73.75 percent; 10 days: 72.5 percent; and 13 days: 65 percent. For seedlings planted on the same site on the same days with dibbles, survival rates were 66.25 percent, 75 percent, 70 percent, 60 percent, 77.5 percent, and 80 percent.

Height Growth Initiation

Height growth initiation was recorded 1 year after outplanting. Height growth was exhibited by 23 percent of seedlings planted with shovels and 22.4 percent of seedlings planted with dibbles after one growing season. Height growth initiation by implement by day is detailed in table 3 and depicted graphically in figure 3.

DISCUSSION

General Conditions

This study was begun just prior to a major catastrophic event, Hurricane Opal, which caused the compression of the site preparation treatments and subsequent outplanting into a much shorter time frame than desired. Planting only 1 month after the bedding operation allowed very little settling of the beds and was a cause of concern. In addition, the burn was conducted only 2 months after the herbicide treatment, likely compromising the effectiveness of the chemicals. Good rains accompanied and followed the planting operation, with 1 inch falling on the day before planting began and nearly 2 more inches falling during the 2-week planting period. Nearly a month passed before the next rainfall on March 7.

Planting Productivity

Planting productivity varied widely from day to day but mean planting productivity did not differ significantly between implements. Variations might best be explained by within- and between-site variations (amount of coarse

Table 3—One-year height growth initiation by implement and by storage time

Implement	Storage time	Height growth
		Percent
Shovel	0	51.4
Dibble	0	34.3
Mean	0	42.9
Shovel	1	36.4
Dibble	1	39.7
Mean	1	38.1
Shovel	3	10.5
Dibble	3	28.3
Mean	3	19.4
Shovel	6	12.0
Dibble	6	31.7
Mean	6	21.9
Shovel	7	7.9
Dibble	7	12.5
Mean	7	10.2
Shovel	9	7.6
Dibble	9	8.3
Mean	9	8.0
Shovel	10	10.0
Dibble	10	11.3
Mean	10	10.7
Shovel	13	11.1
Dibble	13	7.8
Mean	13	9.5
Mean (shovel)		23.0
Mean (dibble)		22.4

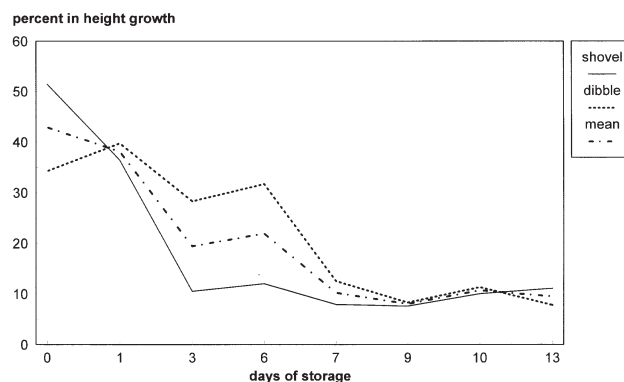


Figure 3—Height growth initiation by planting implement and storage time after one growing season.

woody debris, etc.), weather conditions, individual planter capability, and varying enthusiasm for the project. Suggestions that the less-productive crew always seemed to include the principal investigator I choose to discount as scurrilous rumor.

Survival

Survival was at acceptable levels for operational purposes throughout the study. Survival at 1 year did not differ for implements across both sites and no significant trend could be detected for storage time. Survival did drop after 1 day of storage, but trees stored longer were planted on a different site. Survival of trees with longer storage times varied so much that no statistically significant trend could be identified.

Height Growth Initiation

Early height growth is generally deemed desirable for longleaf seedlings. Decreased exposure to brown spot needle blight (*Scirrhia acicala*) is one result, and early height growth is often thought to be an indicator of continued vigor through the life of the tree (Boyer 1988). Although the confounding effects of site and site preparation differences make statistical analysis risky, there is a relatively strong indication of an inverse relationship between storage time and early height growth initiation. There was no difference in rate of height growth initiation between seedlings planted with shovels and those planted with dibbles.

CONCLUSIONS

Machine planting of these sites was impossible because of the amount of coarse woody debris incorporated into the

beds by the Savannah 3-in-1 plow. Hand planting was accomplished successfully with both shovels and dibbles and no differences were detected between implements in planter productivity, seedling survival, or height growth initiation. Survival was best when seedlings were outplanted quickly after lifting, although no compelling trend was noted. Height growth initiation seemed to be linked fairly strongly to storage time, with early outplanting leading to increased incidence of first-year height growth. The combination of the Savannah 3-in-1 plow treatment, high-quality seedlings, good seedling care and proper planting techniques, and good soil moisture conditions can yield success in establishment of longleaf stands using bare-root seedlings and hand planters.

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DISEASES OF FOREST TREES: CONSEQUENCES OF EXOTIC ECOSYSTEMS?

William J. Otrosina¹

Abstract—Much attention is now given to risks and impacts of exotic pest introductions in forest ecosystems. This concern is for good reason because, once introduced, an exotic pathogen or insect encounters little resistance in the native plant population and can produce catastrophic losses in relatively short periods of time. Most native fungal pathogens of forest trees have co-evolved for eons with their hosts and have reached a sort of balance between them and populations of susceptible tree species. Recent studies on various forest types have indicated a higher incidence of certain fungal pathogens than were previously thought to occur. These pathogens are either the type not normally thought of as highly virulent or are those that have not been previously reported as a serious problem on a particular host. For example, pathogenic fungi belonging to both the *Leptographium* complex and *Heterobasidion annosum*, are associated with mortality after prescribed burning in certain longleaf pine stands. Yet, this tree species has traditionally been ranked as highly tolerant to these fungi. Could these observations reflect some manifestation of “exotic ecosystems,” whereby the conditions under which particular tree species evolved are no longer present or are altered in some way that increases their susceptibility to these fungi? With the current emphasis on ecosystem restoration and alternative silvicultural regimes, it is critical to address such questions in order to avert losses in forest productivity.

INTRODUCTION

Forest tree species and all other living organisms have evolved under various environmental conditions through eons of time. Nearly all species that have ever lived are now extinct (Raup 1986). Adaptations to climatic factors, soils, pests, diseases, and a host of disturbance events, operating at a variety of scales, have forged the characteristics of each tree species we now observe, including their functions in forest ecosystems.

From the perspective of forest pathological processes, individual tree species and ecosystems are in some form of quasi-equilibrium with various pathogens. This is in contrast to situations involving introduced pests or exotic organisms, which generally cause rapid and catastrophic mortality on native tree species. On the other hand, many root disease pathogens that have co-evolved with their hosts often cause excessive mortality and disruption of long-term stand management goals. Why then, in a theoretically stable system from the host-pathogen perspective, are there significant problems with various diseases in coniferous forest stands over a wide range of forest types and ecological conditions? Have presettlement forest conditions changed, through past land uses, to the extent that unstable or “exotic ecosystems” are created by various management activities which have led to undesirable losses due to various forest tree diseases?

For many decades, forest pathologists have studied the effects of various management regimes and their relationships to forest tree disease. As a result, an empirical understanding of relationships between site factors, disturbance, past and present management practices, and silvicultural procedures relative to many forest diseases has been attained. In the light of these discerned relationships, the purpose of this paper is to introduce the concept of exotic ecosystems, defined as unstable ecosystems arising from rapid edaphic and environmental changes brought about by past land use or

current management practices. These will be presented in the context of how various silvicultural regimes, disturbances, and past land use practices have interacted to create disease problems.

ROOT DISEASE

Annosus Root Disease

Caused by the fungus *Heterobasidion annosum* Fr.(Bref.), this disease is often devastating on temperate zone conifers worldwide. Two biological species of this fungus occur in western North America. One, called “S,” attacks primarily true firs and Sequoia while the other, called “P,” attacks mainly pines and juniper. In the Eastern United States, only the P group has been found to date.

The fungus attacks pines (P group) by spores landing on freshly cut stump surfaces. The spores germinate and rapidly colonize portions of stumps, with mycelia growing downward and further colonizing stump roots. Healthy trees whose root systems contact infected stump roots become infected, thus creating ever-widening gaps or disease centers in affected stands (Otrosina and Cobb 1989). Based upon isozyme and DNA studies (Otrosina and others 1992, 1993; Garbelotto and others 1996), the P group in the Western United States was probably rare until presettlement times. It may have occupied niches created by natural wounding events such as blowdowns or possibly fire scars and was a part of Western United States pine ecosystems, creating occasional openings in stands.

By the late 19th century, timber harvesting was conducted on a large scale. Another boom in timber harvesting occurred during the 1950's as a result of post-World War II housing demand (MacCleery 1992). As a result, freshly cut stump surfaces were created in large amounts over 40 to 50 years in old-growth east-side Sierra Nevada pine stands. Many of these stands were subjected to selective harvesting with repeated entries. These partial cutting

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techniques often resulted in stem-damaged residual trees, soil compaction, and root damage. Because fresh stump surfaces are an ideal niche for *H. annosum* colonization, populations of the P group increased dramatically, increasing the likelihood of disease transmission to residuals by root contacts with infected stump roots. The fungus, once in a stand, is intractable and can survive for over 60 years (Otrosina and Cobb 1989). Thus, stand development is affected far into the rotation with the disease perpetuating itself by continued spread in ever-widening mortality centers.

Fire exclusion also has affected annosum root disease incidence in many stands. For example, a general shift in species composition has taken place in the Sierra east-side forest type as a result of fire exclusion. Once park-like stands of predominantly ponderosa pine are now dominated by shade-tolerant, true fir species (Petersen 1989). The S biological species of *H. annosum* is widespread on true firs (Otrosina and Cobb 1989, Otrosina and others 1992) and apparently infects firs more frequently as a result of direct infection through natural wounds or means other than freshly cut stumps (Garbelotto and others 1996). This is in contrast to the P group of *H. annosum* in pine species, which had a more restricted range on pines prior to management activities. The characteristically overstocked stands of firs resulting from fire exclusion have a high incidence of root disease that renders them susceptible to catastrophic insect outbreaks (Hertert and others 1975) and wildfires (Otrosina and Ferrell 1995). Thus, fire exclusion can be thought of as a disturbance resulting in an exotic ecosystem in which current tree species assemblages exist in a pathologically, entomologically, and silviculturally unstable system driven by widespread root disease.

Another example of exotic ecosystems arising from fire exclusion and the presence of root disease is the present decline in health of *Sequoiadendron giganteum* (Lindl.) Buckholz stands in the Sequoia-Kings Canyon National Park. Decades of aggressive fire exclusion have encouraged the ingrowth of shade-tolerant true firs under old growth *S. giganteum*. Because true firs can be infected with the *H. annosum* S group in the absence of harvesting or thinning activities, the resultant presence of firs in sequoia stands may be responsible for transmitting the fungus to the sequoia via root contacts (Piirto and others 1992). Normally, periodic fires would minimize the true fir component in these stands, thereby reducing the risk of transmission of *H. annosum*.

LONGLEAF PINE, FIRE, AND ROOT DISEASE

Leptographium spp. and *Heterobasidion annosum*

Longleaf pine (*Pinus palustris* Mill.) once occupied over 30 million hectares throughout the Southern United States. At present, only about 5 percent of the original longleaf pine sites are occupied by this species. Changes in land use such as agriculture, commercial development, and conversion to other forest species such as loblolly pine (*P.*

taeda L.) and slash pine (*P. elliotii* Engelm.) have contributed to the dramatic decrease in the range of longleaf pine.

Fire is an essential component of longleaf pine ecosystems, being necessary for the establishment of reproduction and for maintaining stand health. This tree species co-evolved with fire as an essential component of its life cycle. Over the past several years, increased mortality has been reported to occur in certain stands, and this mortality appears to be associated with prescribed burning (Otrosina and others 1995). A preliminary research study conducted on a 40-year-old longleaf pine stand at the Savannah River Site in New Ellenton, SC, revealed that burned plots had three times greater mortality 1 year post-burning than unburned check plots. Histological observations on fine roots (<2 mm in diameter) of longleaf pine obtained from the upper few centimeters of soil in the relatively cool burns have shown internal tissue damage when compared to roots from unburned check plots (Otrosina and others 1995). Also, twofold to threefold differences in isolation frequency of the root pathogens *H. annosum* and *Leptographium* species were associated with roots of mortality trees (Otrosina and Ferrell 1995). A recent follow-up study on these plots 3 years post-burn revealed a still higher isolation frequency of *Leptographium* species as compared to check plots (fig. 1). *H. annosum* also was isolated in higher frequency in burn plots 3 years post-treatment, although at a lower frequency than 1 year after burning (fig. 1).

The association of *Leptographium* species with fire and mortality is significant because this fungal genus contains many forest tree root pathogenic species which have varying degrees of pathogenicity toward pine species (Harrington and Cobb 1988, Nevill and others 1995). Many

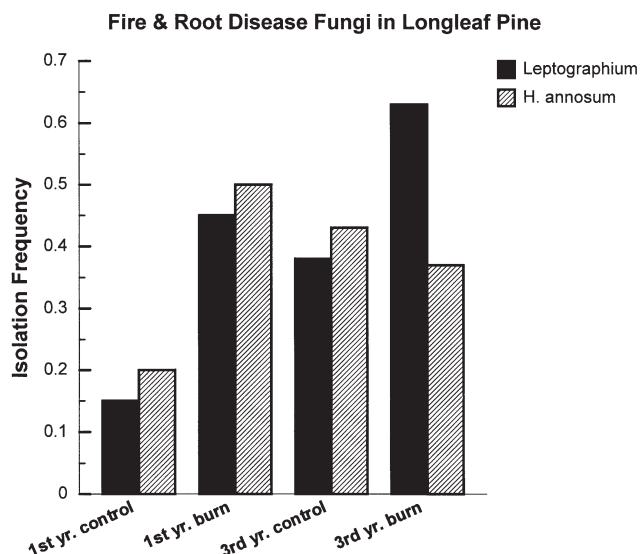


Figure 1—Isolation frequency of *Heterobasidion annosum* and *Leptographium* species in 40-year-old longleaf pine. Data were taken 1 and 3 years after burning in prescribed burned and unburned research plots at the Savannah River Site, New Ellenton, SC.

Leptographium species are also associated with various species of root-feeding bark beetles which can serve as vectors or as wounding agents that allow introduction of root pathogenic fungi (Harrington and Cobb 1988). Observations of insects in larger woody roots of post-fire longleaf pine have been documented (Otrosina and others 1995) but their roles with respect to these fungi and longleaf pine mortality have not been established.

Regarding these associations with fire, fungi, and insects in longleaf pine, obvious questions arise. Why, in a tree species that is adapted to and has evolved with fire, are we observing root pathogens and associated mortality in such high frequency? What are the roles of these various fungal species and insects in relation to the observed longleaf pine mortality? Longleaf pine has been regarded as either tolerant or resistant to root disease (Hodges 1969) and prescribed fire has been reported to decrease incidence of annosum root disease in southern pines (Froelich and others 1978).

Observations based upon windthrown trees suggest that on some sites, severe erosion of up to 2 feet of top soil may have severely restricted longleaf pine root systems to the upper 60 to 70 cm of soil profile (Otrosina unpublished data). Longleaf pine has evolved in deep sands and develops an extensive tap root system in these soils. Thus, although regenerated within physiographically correct sites, longleaf pine on eroded soils are forced into a new ecosystem structure, an exotic ecosystem, with respect to current soil conditions. These conditions, in turn, may produce unstable and unpredictable outcomes when standard management practices are employed. Precisely what relationships exist between fire, mortality, root disease fungi, and soil conditions form the basis for now ongoing research.

IMPLICATIONS

There are many more examples in forest pathology and entomology where man has unknowingly created certain conditions whereby native organisms, both fungal pathogens and insects, have become serious problems threatening forest sustainability (Goheen and Otrosina 1997, Otrosina and Ferrell 1995). The activities of man have rapidly and dramatically changed landscapes and ecosystems over a short period of time. The adaptations developed over eons of evolutionary time in forest tree species may no longer serve these species when forced into sometimes radically "new" ecosystem structures. These new structures are characterized by interactions not experienced by the tree species in an evolutionary sense, resulting in an unpredictable and unstable or chaotic system (Moir and Mowrer 1995) susceptible to various and unexpected disease problems. The exotic ecosystem concept put forth here is a new viewpoint on subjects contemplated by forest pathologists, entomologists, and silviculturists, encompassing well-known abstractions such as predisposing factors, stress, disturbance regimes, and sustainability.

Some viewpoints regarding endemic forest tree root diseases embrace the idea that because these disease causing fungi are endemic to forest ecosystems, they perform beneficial functions among which are creating gaps in forest canopies, decomposing woody debris, or producing cavities for wildlife. These views assert, depending upon management objectives, that root diseases may or may not be detrimental. Such a notion presumes their function and regulatory dynamics are the same at present as they were prior to various management activities. Nevertheless, attention must be granted to the issue that some ecosystems may now be comprised of tree species that are maladapted to current conditions, resulting in varying degrees of instability.

For example, after years of successful wildfire suppression and politically motivated resistance to use of prescribed burning as a silvicultural tool, many forest stands whose natural history involved periodic burning now have large accumulations of litter and fuel. The recent focus on forest health issues acknowledges the importance of fire in many forest ecosystems and are recommending reintroduction of fire to these stands. Forest stands in these situations should be regarded as exotic ecosystems with the appropriate caution exercised. The new set of initial conditions may bring about unexpected forest health problems when fire is reintroduced in many stands. On the other hand, many forest ecosystems are quite resilient and stable under various management regimes; however, it is imperative that we strive to understand disease processes resulting from these new sets of conditions in order to identify the ecosystems and related conditions under which instability and unpredictability develop.

ACKNOWLEDGMENT

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FIRST STEPS IN DEVELOPING JABBERWOCKY: A THREE-DIMENSIONAL, BIOLOGICALLY BASED INDIVIDUAL TREE MODEL FOR LONGLEAF PINE

Rick Smith and Greg L. Somers¹

Abstract—A three-dimensional, biologically based model for longleaf pine is being developed for natural resource managers at Eglin Air Force Base. The model has two purposes. It will provide “traditional” growth and yield functionality for defining management of existing longleaf stands. What is more important is it will serve as a simulator to aid managers at Eglin in defining preferable ecosystem management strategies and developing a sustainable ecosystem.

We present the general structure by the model to provide an understanding of how the biological basis and spatial detail of the model will provide the functionality required by a forest ecosystem simulator. The primary components of the system are tree, climate, solar radiation, and soil. We will spatially model all components of the tree, that is, crown, roots, bole. Three integrated geometric models are being used to facilitate the calculation of resource availability and growth.

We describe the data and the measurement methods being used to collect the wide range of variables necessary for the spatial detail required by this model.

INTRODUCTION

Ecosystem management has restructured public land managers' thinking on forest land management. The shift in emphasis from single-rotation monoculture management to ecosystem management has found both forest land managers and researchers lacking in knowledge, tools, and training. As we move to ecosystem management the modeling of a wide range of spatial and temporal scales is necessary. The processes that compose an ecosystem range from physiological processes operating in milliseconds to forest succession covering hundreds of years. The spatial and temporal resolution of existing models is limiting. Most existing models use multiyear measurements until harvest for development. The unit in these models is the stand. Size-class distributions represent the trees in the stand. A tree's size-class predicts its other characteristics. Existing longleaf pine models do not provide the juxtaposition of individuals in the stand or other detailed spatial information. Ecosystem management requires predictions of processes other than just tree growth. These “other” processes demand more spatial detail than is possible in a stand model. Similarly, the single-rotation multiyear temporal scale of existing models will not allow the modeling of physiological or successional processes due to the differing scales of time.

The demands of ecosystem management of longleaf pine stands require a model to provide management guidelines and integrate a wide range of research. It is imperative that the resulting model be able to integrate a large body of present and future independent research for the evaluation of management practices and how they alter the ecosystem.

Unquestionably, a system as complex as an ecosystem will never allow the development of a model that can incorporate all agents and processes. This is impossible because future research and changing environmental conditions will constantly change our understanding of the

processes and agents that compose an ecosystem. In response to this problem, model development methods are being used that will allow the model to evolve. Appropriate model development methods will allow the model to grow with ecosystem management research. It is with these considerations, problems, and goals in mind that the Jabberwocky model is being developed.

BACKGROUND

A great deal of thought and energy has gone into the design of Jabberwocky. To understand the reasoning leading to the form of the model we must understand the problems being addressed. We divide these problems into biological, data, and design considerations.

Biological Considerations

One goal of this research is to develop a model that is applicable to any stand structure, for example, even-aged, uneven-aged, shelterwood, thinned, etc. This goal is the primary reason for taking an individual tree approach. The basis of the model is the individual tree because a tree is an autonomous biological unit with clearly defined components. A stand is the result of the interactions of the individuals. If we can accurately model the interactions of one tree on another then it is possible to develop a model that is applicable to any stand structure. This is the biggest challenge being addressed in the development of this model. The accurate modeling of competition requires a great deal of spatial information. Thus, Jabberwocky must be a three-dimensional, individual-tree model.

The long-term goal of Jabberwocky evolving to an ecosystem model requires the model to be compatible with data sources covering a wide range of spatial and temporal scales. The spatial models being developed will provide the ability to model a wide range of processes without redeveloping the model, but rather by adding functionality.

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Another goal of this project is to develop a model that is usable throughout the natural range of longleaf pine. If there is to be any hope of achieving this goal, Jabberwocky must incorporate the environmental factors of growth and the biological bases of stand dynamics. The existing models of longleaf pine stands are predominantly empirical in their form. They are very precise predictors. However, they tend to be poor performers in regions where the model is uncalibrated. We believe we can make reliable extrapolations by using biological drivers.

Data Considerations

The model is being developed in the next 5 years for the managers at Eglin Air Force Base. This eliminates the use of fixed-area plots. The slow growth rates in the sandhills require a minimum 5-year remeasurement period. Stem analysis is being used to rapidly collect bole and branch growth data for the last 5 years for trees scattered throughout the base. The need for detailed crown architecture data also requires that destructive methods be used to map the crown in detail. While using destructive measurements for model development, we require fixed-area plot data for validation and evaluation of the model. As mentioned, one goal is to develop a model for use throughout the natural range of longleaf pine. The destructive measurement of individual trees is an efficient method for collecting data across the range of conditions on Eglin. These methods also provide an efficient approach for collecting data across the natural range of longleaf pine.

Design Considerations

The limited capabilities of humans to understand complex systems also limit ecosystem models. The complexity of an ecosystem is one, if not several, orders of magnitude greater than anything expressed in existing longleaf pine models. We must understand complexity and use its attributes to our advantage to be successful in modeling an ecosystem. Software engineers have devoted much time and energy to developing an understanding of complex system methods that improve the development process of large software systems. The result is a list of attributes that all complex systems share (Booch 1994). These attributes are:

- (1) A complex system is hierarchical in form—"Frequently, complexity takes the form of a hierarchy, whereby a complex system is composed of interrelated subsystems that have in turn their own subsystems, and so on, until some lowest level of elementary components is reached" (Courtois 1985).

We can decompose a complex system into a hierarchy that will allow us to define the basic components of a system and more easily examine the system and its structure.

- (2) A system's primitive components are arbitrary and up to the observer—"The choice of what components in a system are primitive is relatively arbitrary and is largely up to the discretion of the observer of the system. What is primitive to one observer may be at a much higher level of abstraction for another" (Booch 1994).

The decomposition of a system strictly depends on the needs and interests of the person analyzing the system. There are no absolutes defining the components a model should contain.

- (3) Intracomponent linkages are stronger than intercomponent—"Intracomponent linkages are generally stronger than intercomponent linkages. This fact has the effect of separating the high frequency dynamics of the components—involving the internal structure of the components—from the low-frequency dynamics—involving interaction among components" (Simon 1982).

The difficulty with analyzing complex systems is the difficulty people have with simultaneously considering a large number of processes. If we can isolate a subsystem and analyze it without having to consider the influence of other subsystems on it, we can focus more clearly on the subsystem being studied.

- (4) Hierarchic systems contain a few different kinds of subsystems—"In other words, complex systems have common patterns. These patterns may involve the reuse of small components, such as cells found in both plants and animals, or of larger structures, such as vascular systems, also found both in plants and animals" (Booch 1994).

These common patterns allow us to reuse portions of a model to expand. We do not have to "recreate the wheel." It is only necessary for the person analyzing the system to realize the commonality of the patterns in the system.

- (5) Stable complex systems evolve from simple systems—"A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over, beginning with a working simple system" (Gall 1986).

It is important that the ecosystem model be developed in increments. It must start as a simple model and slowly, through incremental development, gain the complexity required to model an ecosystem.

An object-oriented modeling approach makes the attributes of a complex system an advantage instead of a difficulty. The Jabberwocky model is being developed through object-oriented analysis, design, and programming.

A biologically based ecosystem model establishes exacting spatial and temporal requirements. The processes that take place within an ecosystem operate at very different time scales from milliseconds to millennia. Using longleaf pine trees as the focus, we can represent most processes on an annual basis without loss of information. However, the development of a complete longleaf ecosystem model is contingent on the ability of the model to be able to run at both small and large time increments. The model must be flexible enough to incorporate predictors of instantaneous

processes (photosynthesis, light availability); daily or within-day processes (water transport, diurnal cycles of gas exchange); yearly, growing season and within-growing-season processes (understory growth, carbon allocation, seed production). Operating a model annually for the period required provides multiyear projections. The model must have a minimum temporal resolution of yearly increments, but it must also have a spatial structure that will allow the modeling of within-year processes. The ability of the model to run on annual increments does not require high spatial resolution. However, within-season processes can require high spatial resolution. The spatial resolution of a model must be proportional to the temporal resolution. No one spatial model can accommodate all these processes. We are developing Jabberwocky using several integrated geometric models to provide the spatial and temporal flexibility necessary.

Existing Models

The Tree and Stand Simulator (TASS) family of models (Mitchell 1975, Goudie 1980) is the basis of Jabberwocky. The three-dimensional crown dynamics, bole growth, and biological representations in TASS provide a solid basis for model development. TASS has many deficiencies for ecosystem modeling. We will adapt and extend the approaches used in TASS. First, the incorporation of light-transmittance and light-extinction models is necessary for modeling shading and its influence on growth for all plants. Second, the TASS model uses site index as a basis for site productivity. The use of site index severely limits the geographical range and the types of stands that the model covers. Jabberwocky is being developed using soil and weather variables to alter the growth trajectories instead of site index, due to this limitation. TASS models stands for a single rotation and does not include a regeneration component. Jabberwocky will contain a regeneration component to allow it to represent naturally regenerated stands.

We will avoid the extensive modeling of root systems. This is due to the lack of available information and the high cost associated with this area of research. Basic models of root structure are being developed from very simple measures of lateral and tap roots. The purpose of this area of research will be to define the edaphic resources available rather than the modeling of structural root dynamics.

The initial model will contain only longleaf pine. We will add other ecosystem components, such as other tree species and understory species, through cooperative modeling efforts with ongoing and planned longleaf research by other investigators at Eglin Air Force Base.

GENERAL DESCRIPTION OF RESEARCH

Crown Architecture, Dynamics, and Modeling

Three spatial models will facilitate modeling of stand, tree, and within-crown processes. A voxel (three-dimensional matrix) model will represent the canopy. Its primary purpose will be to facilitate light environment calculations at the canopy level. A crown model will represent the exterior shape of the crown adjusted for competition and crown

contact. This model will model the variables of greatest interest to most foresters such as height growth and diameter growth throughout the bole. Finally, an "explicit" spatial model will pseudo-realistically model all the features of the tree including bole, branches, foliage, and roots. It will facilitate the modeling of within-crown processes that require a high spatial resolution. The explicit model and the crown model will be compatible. This means the branch tips of the explicit model will be on the hull of the crown model. All the geometric models will share information.

Foliar Dynamics and Distribution

An objective of this research is to develop a three-dimensional leaf area distribution for longleaf pine trees. Many authors have used foliar distributions based on either leaf area or mass for a variety of species (Kinerson and others 1974, Waring and others 1981, Hagihara and Hozumi 1986, Remphrey and Powell 1988). The canopy foliar distribution developed by Kinerson and others (1974) for loblolly pine was based on a vertical negative exponential function. Hagihara and Hozumi (1986) used a vertical Weibull distribution to model the foliar distribution of *Chamaecyparis obtusa* (Sieb. and Zucc.) Endl. These continuous distributions provide a means to model foliar distribution at the stand or canopy level but have little utility for individual trees. Models of a tree's foliar distribution are usually geometric distributions. Mitchell (1975) modeled the distribution of foliage by age by dividing the crown into concentric shells. Goudie (1980) also used this technique. Grace and others (1987) used concentric shells to model foliar distribution as well, but the shells related to photosynthetic capacity. Research will focus on merging these approaches to develop a foliar distribution that will allow a parsimonious, but sufficient, representation of foliage within the crown of a tree.

To understand the relationship between foliage and growth throughout a tree we must understand more than the simple physical properties of foliage. We must know the photosynthetic capacity of the foliage. The measurements of foliage include its spatial distribution and maximum photosynthetic capacity (P_{max}). Authors have found a high correlation of specific leaf nitrogen with photosynthetic capacity in a variety of crops, shrubs, and trees (Field and Mooney 1983, Charles-Edwards and others 1987, Hinckley and others 1992). Research is being conducted on the relationship between foliar nitrogen and its location in the crown. We will develop a refined foliar distribution that will represent not only the leaf area of the tree but also the contribution of foliage at a given location to growth.

Wood Growth, Sapwood, and Distribution

The proportion of respiration to photosynthate production defines the carbon budget and the resulting growth, and possibly death, of a tree. The major consideration of living tissue in a tree is in the foliage and surface of the bole and branches. McMurtrie and Wolf (1983) and West (1987) developed catabolic-anabolic relationships for modeling stand and individual tree biomass dynamics. Whitaker and Woodwell (1967) established the ratio of leaf area to bark surface area as a growth limiting factor. Westman (1987) used procedures modified from Whitaker and Woodwell to

compare the net productivity of red fir (*Abies magnifica* A. Murr.) and white fir [*A. concolor* (Gord. and Glend.) Lindl.]. Keane and Weetman (1987) also concluded the ratio of leaf surface area to wood surface area played an important role in the net productivity for different stocking levels of lodgepole pine (*Pinus contorta* Dougl. ex. Loud). Woody surface area distributions and growth relationships in combination with foliage are critical components for developing a spatially explicit, biologically based, individual-tree model. Similarly, we will model growth on the bole using the branch and leaf area distributions.

There are two reasons to model the relationship of sapwood basal area to leaf area throughout the bole. The first reason is to provide a means to predict the leaf area and increase the sample size for bole growth measurements at minimal effort. Second, it will allow us to incorporate the pipe model as a mechanism to influence and control growth. Shinozaki and others (1964a, 1964b) published the original version of the Pipe Model. Simply stated, there is a proportional amount of unit thickness pipes to each unit of leaves. This theory provides an easy method for estimating leaf surface area (Waring and others 1981, Blanche and others 1985). Image analysis is being used to measure sapwood basal area on the sample discs. An evaluation is underway to define which methods are the most reliable and consistent for sapwood area measurement. Leaf area is being measured by systematically sampling age cohorts of foliage throughout the crown. Measures of conductance along the bole will be taken in the future to calibrate the pipe model component of the model.

Destructive Sampling Methods

The destructive sampling methodology used by Mitchell (1969, 1975) and Goudie (1980) is the basis for collecting the data for the longleaf model. Their field methods provide a launching point for this study. We collect diameter growth data along the bole by stem analysis. To obtain detailed crown architecture information, we remove branches from the crown while the tree is standing. We tag the branches before removal to allow repositioning on the bole for mapping. We next cut and lower the branches to the ground. Branch removal continues to a bole diameter of approximately 4 inches. We next top the tree and lower the top to the ground. Finally, we fell the tree and cut it into sections. To measure the architecture, we place the sections in their original orientation on the ground. Then we clamp the branches back on the bole. We reconstruct the growth history of each branch by three-dimensional mapping. The methods of Maguire and Hann (1987) and Kershaw and others (1990) are being used to determine branch mortality. This is required to provide the data necessary to model the change in the base of the live crown due to competition (crown rise), and to estimate the leaf area of the crown in the past, which is used for developing growth equations. We weigh all the tree components. We remove discs at 1-meter intervals along the bole and on a subsample of branches. We measure the discs of ring area, sapwood basal area, and conductance. We measure annual rings and sapwood by image analysis.

Light Environment

We will incorporate light measurements in later stages of the study. We will collect light measurements by a combination of hemispherical photographs and photoelectric diodes. A double sampling and subsampling with these tools will provide light environment measurements within and below tree crowns. A hemispherical photograph analysis system and methods developed by Smith and Somers (1993) provide a method to take and interpret the hemispherical photographs. We will use light data in combination with the foliar and wood distribution to define how the foliage and branches influence the light environment and vice versa.

Weather and Soils

National Oceanic and Atmospheric Administration data and any local weather data will drive the model. We measure the soils at all study locations. The soil is analyzed for both physical and nutrient properties. The relationship of the physical properties of the soil to growth is of great importance because of the greater ease of measurement. This will help ensure the model's utility over a wide range of sites. We will not include soil dynamics over time in the model initially, due to its complexity.

Model Analysis and Specification

We must consider the long-term expansion of the model to an ecosystem in its development. We are using a formal method to provide a specification of the system. This is the first step in a formal process to guarantee the development and continued utility of the model as it evolves to an ecosystem model.

Software engineering is the development of a software system by teams using sound engineering principles and techniques to produce a correct, reliable, and maintainable product by a proven method (Somerville 1992). Problems in the development of a large software system parallel the problems encountered in the development of an ecosystem model. The development of an ecosystem model will require a team effort by researchers using scientific principles and techniques to produce a correct and reliable understanding of ecosystem processes. However, there is nothing inherent in the scientific method that guarantees the maintainability of the resulting model. There is not a proven method to use for such a comprehensive task. Software engineering provides a process that can help guide the development process and aid in all stages of model development. This development process is the software lifecycle or waterfall model. This process is being adapted to the needs of ecosystem model development (fig. 1).

The phases of the waterfall model are analysis, design, implementation, maintenance, and testing. The waterfall model does not allow for incremental development. The development process is over once the software system is implemented and the system is being maintained. Thus, the original waterfall model includes only those paths along the waterfall (fig. 1). We add a path from maintenance to analysis to allow incremental development and a simulation phase. The simulation phase is necessary to help in

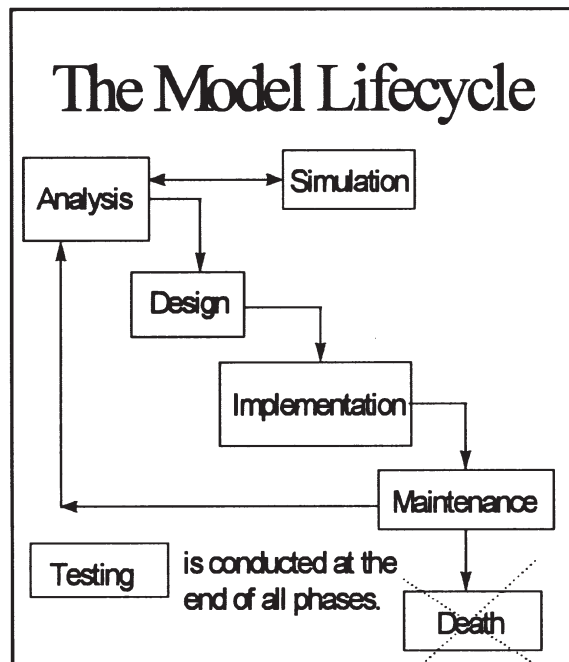


Figure 1—The incremental model.

defining the requirements and to provide guidance for future research. The purpose of the analysis phase is to define the requirements of a system in detail through text and diagrams. The diagrams represent the processes in the model, the objects in the model, and the flow of information between them. Decomposing an ecosystem by focusing on the objects that form it is object-oriented analysis. Object-oriented modeling is being used to develop the model because it takes advantage of the attributes of complexity described earlier. It lends itself more naturally to a hierarchical decomposition that will allow us to isolate and focus on ecosystem components independent of the influence of other components. The incremental development process works by modifying and reusing objects for model expansion.

The Fusion method (Coleman and others 1994) is being used for object-oriented model development. We selected Fusion from many possible object-oriented methods due to its complete approach, from analysis to maintenance and redevelopment, and its clear demarcation of phases of development. The first phase of the Fusion method is the development of the object model, lifecycle model, and operational model to represent the object-oriented decomposition of the system.

DISCUSSION AND CONCLUSIONS

The research to collect the data necessary for the development of Jabberwocky is off to a healthy and fruitful start. The data collection phase will continue for the next 3 years to obtain a minimum of 120 trees. Future areas of data collection are light, roots, and sapwood conductance. While the general form of the model and the functionality it must provide are clear, there is a great deal of work to be done on its design and implementation.

The current focus of this research is on developing a model for Eglin Air Force Base. The long-term goal is the development of a system for the natural range of longleaf pine to model not only the stand, but the entire ecosystem.

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THIRTY YEARS OLD—THE REGIONAL LONGLEAF PINE GROWTH STUDY

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Abstract—From 1964 to 1967, the USDA Forest Service established the Regional Longleaf Pine Growth Study in the Gulf States. The original objective was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine (*Pinus palustris* Mill.) stands. Initially, 185 plots were installed to cover a range of ages, densities, and site qualities. Plots are remeasured on roughly a 5-year cycle. A total of 305 plots are now in the study. They are located in central and southern Alabama, southern Mississippi, southwest Georgia, northern Florida, and the sandhills of North Carolina. Within this distribution are four time replications of the youngest age class that have been installed to detect growth changes over time. All four time replications are located on the Escambia Experimental Forest in Brewton, AL. The original study has been expanded to include the development of taper equations, site index curves, pole prediction models, and pine straw production models. As part of the Southern Global Change Project, the Regional Longleaf Pine Growth Study plots and database were used to examine the impacts of climate (precipitation and atmospheric temperature) on longleaf pine productivity in relation to stand age, site quality, and stand density. As a part of this project, studies related to longleaf pine needle fall, specific leaf area, and projected leaf area were conducted. Studies were also conducted to determine the stability of parameters in growth models over time and the inclusion of weather variables in growth models. The Regional Longleaf Pine Growth Study project represents a stable long-term data base and an active “field laboratory” for natural, even-aged, longleaf pine stands. The value of this project increases as more and more ownerships in the South consider longleaf pine management alternatives. Public and private land managers are seeking a range of ecological and economic outcomes related to the restoration, rehabilitation, and regeneration of longleaf pine.

INTRODUCTION

In 1964, the USDA Forest Service established the Regional Longleaf Pine Growth Study (RLGS) in the Gulf States. The original objective of the study was to obtain a database for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine (*Pinus palustris* Mill.) stands. Plots were installed to cover a range of ages, densities, and site qualities. The study accounts for possible growth change over time by adding a new set of plots in the youngest age class every 10 years. The project is in its sixth measurement period (30-year measurement). Research utilizing this existing longleaf pine database has been expanded to include utility pole and pine litter production.

METHODS

The study consists of 305 permanent 1/10- and 1/5-acre measurement plots located in central and southern Alabama, southern Mississippi, southwest Georgia, northern Florida, and the sandhills of North Carolina. Plot selection was based upon a rectangular distribution of cells formed by four stand-age classes ranging from 20 to 80 years, five site-index classes ranging from 50 to 90 feet at 50 years, and five density classes ranging from 30 to 150 square feet per acre. The oldest plots will be in the 120-year age class with the completion of the current 30-year remeasurement.

Within this distribution are four time replications of the youngest age class. All four replications are located on the Escambia Experimental Forest in Brewton, AL. As a part of the RLGS, plots in the youngest age class were first established in 1964 and new sets of plots have been added in this age class every 10 years. Plots are located to achieve similar initial site qualities and ages, and are thinned to their target basal areas.

At the time of establishment, plots are assigned a target basal area class of 30, 60, 90, 120, or 150 square feet per acre. They are left unthinned to grow into that class if they are initially below the target basal area. In subsequent remeasurements, the plot is thinned back to the previously assigned target if the plot basal area has grown 7.5 square feet per acre or more beyond the target basal area. The thinnings are generally of low intensity and are done from below.

Net (measurement) plots are circular and 1/5-acre (14 net plots are 1/10-acre) in size surrounded by a similar and like-treated half-chain wide isolation strip, with both surrounded by a half-chain wide protective buffer strip that receives extensive management. Plots are inventoried, and treated as needed, every 5 years. The measurements are made during the dormant season (October through March) and it takes 3 years to complete a full remeasurement of all plots. Cooperators are asked to use cool, winter burns on a 3-year cycle to control hardwood competition.

Each tree on the net plot with a d.b.h. >0.5 inches is numbered by progressive azimuth from magnetic north and has its azimuth and distance from plot center recorded. At every remeasurement, each tree has its d.b.h. recorded to the nearest 0.1 inch, and its crown class and utility pole class and length determined. A systematic subsample of trees from each 1-inch d.b.h. class has been permanently selected and measured for height to the live-crown base, total height, and, if the tree is dominant or co-dominant, for age from seed.

Associated Studies

The RLGS represents a stable, long-term database and an active “field laboratory” for natural, even-aged, longleaf pine

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stands. The value of this project increases as more and more ownerships in the South consider longleaf pine management alternatives. Public and private land managers are seeking a range of ecological and economic outcomes related to the restoration, rehabilitation, and regeneration of longleaf pine. The plots are also available for cooperative studies that would not harm the plots or interfere with future activities. An example is our USDA Forest Service Southern Global Change Program (SGCP)/RLGS project (which is nearing completion). This study was undertaken to examine the productivity of natural stands of longleaf pine in relation to competition and climatic factors.

Using the existing RLGS plots and database, the project is investigating the relationship between productivity (biomass) of natural stands of longleaf pine in relation to stand age, site quality, stand density (competition), and the climatic factors of precipitation and atmospheric temperature. A major component of the SGCP project was to examine longleaf pine litter (pine straw) production. Needle fall has been monitored monthly since August 1992 via litter traps on a representative subsample of plots across the range of site, age, and density combinations. Efforts are underway to model annual litter production (tons per acre, dry weight) as a function of stand variables. The results from the various components of the project will be published as individual manuscripts.

Other studies directly associated with the RLGS sites include: (1) soil samples have been taken on the RLGS plots to provide baseline data and to improve estimates of site productivity; (2) utility pole information is being used to develop relationships between stand characteristics, thinning activities, and pole production; (3) efforts are being completed to improve estimates of longleaf pine taper equations by including crown ratio as an independent variable; (4) data are being examined in an effort to improve the estimates of site index for naturally regenerated longleaf pine stands; (5) basal area and mortality models are being developed to improve the predictions of stand dynamics; (6) prescribed burning history has been added to the database; (7) old-growth stands are being identified and measured to improve estimates of growth and mortality for longer rotations and to assess the stability of old-growth stands; and (8) economic projections are being developed.

RESULTS

The 30-year remeasurement is nearing completion. Efforts continue to examine longleaf pine litter (pine straw) production, which was a major component of the SGCP; and utility pole production, which was an addition to the 25-year measurement cycle.

Over the course of the RLGS, several stand and individual tree-level models have been developed to provide data to evaluate management alternatives. Individuals interested in predicting stand growth and mortality are directed to the works of Farrar (1979, 1985), Somers and Farrar (1991), Farrar and Matney (1994), and Quicke and others (1994 and in press). Work will continue to incorporate new data

and refine growth relationships as new models are developed.

Through the 25-year remeasurement, there are 28 publications and numerous presentations that are a direct result of the RLGS. Another 14 related publications use information from the RLGS. (The Appendix provides a listing of these.)

CONCLUSION

The RLGS has adapted to changes in the resource base and shifting public concerns over the last 30 years. The initial installation in the mid-60's resulted in 185 sample plots. This number increased to 267 in 1986 and is now at 305. As the number of plots have grown and in response to changing questions, the objectives of the RLGS have expanded. It is no longer meaningful to have growth projection models estimate only to stand-level merchantable basal area and total volumes in pulp and saw timber. Users are demanding more information on multiple products, and want trees per acre and merchantable volume by d.b.h. classes, to answer their current questions. The RLGS is keeping pace with ever-changing demands and is proving once again that well designed, long-term studies are wise research investments.

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HARVESTING LONGLEAF PINE STRAW ON THE KISATCHIE NATIONAL FOREST, LOUISIANA

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Poster Summary

INTRODUCTION

Pine needles (straw) have long been gathered for mulch in the Southern United States. Harvesting of pine straw can substantially increase profits from management of small forest holdings. However, repeated removal of pine straw from the forest floor may reduce timber yields. Since timber prices are high and expected to remain so for several years, management should ensure good timber growth. The objective of this study was to determine how pine straw harvesting practices influence longleaf pine (*Pinus palustris* Mill.) productivity, nutrition, and needle cast.

PROCEDURES

The 40-ha study site is on gently rolling ground in Rapides Parish, LA. Soils are Ruston and Smithdale (Typic Paleudults) sandy loams. The longleaf pine stands on the site originated from direct seeding in 1956. From the time of seeding, the site was prescribed burned triennially as part of a range management program. Burning retarded development of woody vegetation in the understory.

We installed a randomized, complete block, split-plot design with four blocks as replicates in the spring and early summer of 1990 (Haywood and others 1995). The two main-plot treatments within each block were: (1) no fertilizer applied and (2) 50 kilograms per hectare (kg per ha) nitrogen (N) and 56 kg per ha phosphorus (P) broadcast evenly over the entire main plot on April 23, 1991, as 280 kg per ha diammonium phosphate fertilizer (DAP). Management of the subplots for pine straw includes: (1) check—no treatment after 1990; (2) burned only—the subplots were burned with strip headfires in March 1991 and February 1994; (3) burned and two straw harvests—in addition to receiving treatment 2, the subplots were rotary mowed and the straw was harvested in early 1992 and 1993; and (4) burned and four straw harvests—the subplots were thinned and mowed in 1990, burned in August 1991, and rotary mowed and harvested annually in early 1992 through early 1995. When straw was to be harvested it was first collected in windrows with a tractor-mounted straight-bar rake and then baled mechanically. The bales were weighed and samples were taken so that moisture

content and dry matter production could be determined (Haywood and others 1995).

In January 1991 and 1996, d.b.h. and tree height of longleaf pines over 10 centimeters (cm) in d.b.h. were measured, and the inside-bark volume per ha (i.b. per ha) was calculated (Haywood and others 1995). Litter traps were used for the monthly collection of needle-fall samples. Nutrient analyses were done on randomly collected samples of soil to a depth of 15 cm and living on needles from the upper crowns of dominant longleaf pine trees. Bulk density samples of the mineral soil were randomly taken to a depth of 10 cm. A rainfall simulator was used to determine infiltration and runoff water quality for a 0.4 meter-square (m²) subplot. Treatment-to-treatment differences in longleaf pine or soil properties were subjected to appropriate statistical analysis.

NEEDLE FALL AND STRAW HARVEST

From 1991 through 1995, 18 percent of the longleaf pine straw consistently fell from January through July (720 kg per ha), and total annual needle fall averaged 4,040 kg per ha. There were no statistically significant treatment-to-treatment differences in average total yearly needle fall. Actual yields of harvested pine straw did not decline with management.

SOIL PROPERTIES

In July 1994, bulk density was significantly greater for the burned-and-two-straw-harvests [1.39 grams per cubic centimeter (g per cm³)] than for the check (1.33 g per cm³) or burned-only treatment (1.34 g per cm³). Bulk density after three harvests (1.44 g per cm³) was significantly greater than bulk density after two harvests. Water infiltration was reduced by harvesting. It averaged 10.3 centimeters per hour (cm per h) on the no-harvest treatments, 6.4 cm per h after two harvests, and 5.5 cm per h after four harvests. Sediment loss, as an index of erosion, and sediment concentration were increased by harvesting. Sediment loss averaged 35 kg per ha and sediment concentration averaged 0.08 grams per liter (g per l) for the no-harvest treatments. After two harvests, sediment loss averaged 125 kg per ha and sediment concentration averaged 0.15 g per l. After four harvests,

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sediment loss averaged 360 kg per ha and sediment concentration averaged 0.39 g per l.

NUTRITION

The application of N and P increased available soil P concentration to 8.63 milligrams per kilogram (mg per kg), compared to a concentration of 2.56 mg per kg on the unfertilized plots. As a result, fertilization also significantly increased the concentration of P in the living needles. The concentration of P in the living needles was 700 mg per kg on the unfertilized plots and 890 mg per kg on the fertilized plots. Harvesting pine straw did not influence soil or foliar P concentrations. Foliar nitrogen concentrations were unaffected by fertilization.

LONGLEAF PINE YIELDS

On the unfertilized plots, 5-year pine growth with four straw harvests was almost 8 m³ i.b. per ha less than 5-year pine growth with no harvesting of straw. However, 5-year pine growth with broadcast fertilization and four straw harvests was almost 2 m³ i.b. per ha greater than 5-year pine growth for the fertilized-no-harvest treatments. The 39 - year-old longleaf pines averaged 215 m³ i.b. per ha of wood volume across all treatments. We believe that the continual harvesting of straw provided weed control, and

the combination of fertilizer and weed control is known to increase pine productivity.

BEST MANAGEMENT PRACTICES

Recommended best management practices for lands where pine straw is harvested are to periodically fertilize with 150 to 200 kg per ha N and 56 kg per ha P, avoid soils with more than 10 percent slopes and streamside areas, and carefully mow and rake to expose less mineral soil. Our findings partly confirm these recommendations, and we support the use of these management practices. Pine straw harvesting lessens fire hazard, provides annual revenue, and if done properly can increase total farm income. Part of this extra income should be used to correct any site damage.

LITERATURE CITED

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RESTORATION OF NATIVE PLANT COMMUNITIES IN LONGLEAF PINE LANDSCAPES ON THE KISATCHIE NATIONAL FOREST, LOUISIANA

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Poster Summary

INTRODUCTION

In January 1993, the Kisatchie National Forest and Southern Research Station began monitoring the effects of various management practices on overstory and midstory trees, shrubs, and understory woody and herbaceous vegetation in several longleaf pine (*Pinus palustris* Mill.) stands. The monitoring of these stands is part of several Ecosystem Management Projects. These projects address the effects of different seasons of burning, group selection cutting, removal of off-site pine species, and shelterwood management on forest vegetation. One of our goals is to identify common plants that are usually present in longleaf pine forests once the silviculturist's objectives are met.

SEASON-OF-BURNING PROJECT

We are monitoring characteristics of vegetation in stands burned periodically in winter, spring, or summer to determine whether management activities are restoring old-growth attributes. On the Catahoula Ranger District (RD), the forests are on gently rolling uplands of Ruston and Smithdale (Typic Paleudults) sandy loams. On the Vernon RD, the forests are on gently rolling uplands of Malbis (Plinthic Paleudult) fine sandy loam. Hardwoods are more numerous on the Catahoula RD than on the Vernon RD. However, the overstories and midstories of the stands are dominated by longleaf pine with scattered loblolly pine (*P. taeda* L.), southern red oak (*Quercus falcata* Michx.), and sweetgum (*Liquidambar styraciflua* L.). Other species that may be present include flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), blackjack oak (*Q. marilandica* Muenchh.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), mockernut hickory [*Carya tomentosa* (Poir.) Nutt.], sassafras [*Sassafras albidum* (Nutt.) Nees], and tree sparkleberry (*Vaccinium arboreum* Marsh.).

In the understory, woody plants and blackberry are kept in check by burning. Species present in significant numbers include southern red oak, flowering dogwood, blackberry (*Rubus* spp.), waxmyrtle (*Myrica cerifera* L.), blueberry (*Vaccinium* spp.), poison oak [*Toxicodendron toxicarium* (Salisb.) Gillis], and grape (*Vitis* spp.). Pine seedlings cannot grow well in these stands because the overstory basal areas range from 98 to 124 square feet per acre (ft² per acre).

The herbaceous species present in greatest numbers are pinehill bluestem [*Schizachyrium scoparium* var. *divergens*

(Hack.) Gould], low panicums (*Dichanthelium* spp.), grassleaf goldaster [*Heterotheca graminifolia* (Michx.) Shinnery], swamp sunflower (*Helianthus angustifolius* L.), goldenrods (*Solidago* spp.), and bracken fern [*Pteridium aquilinum* var. *pseudocaudatum* (Clute) Heller].

GROUP SELECTION AND REMOVAL OF OFF-SITE PINE PROJECT

On five ranger districts, we are demonstrating that group selection and off-site pine removal can restore an uneven-aged structure to longleaf pine forests while sustaining habitat for threatened and endangered species and maintaining a diverse understory of herbaceous and woody plants. Conditions in these longleaf pine stands include a stand with a preexisting uneven-aged structure on the Evangeline RD, even-aged forest adjacent to savanna on the Kisatchie RD, and even-aged forest with a brushy understory on the Winn RD. An analogue of the uneven-aged longleaf pine forest type is the uneven-aged ponderosa pine (*P. ponderosa* Dougl. ex Laws.) forest type of the Western United States. In these forests, there are groups or clusters of trees of similar ages adjacent to other groups of another age class.

SHELTERWOOD PROJECT

On the Catahoula RD, we are monitoring seed crops and understory vegetation in a longleaf pine shelterwood with reserves. This shelterwood is on a Ruston and Smithdale rolling upland and has 35 ft² of basal area per acre. It was retained for red-cockaded woodpecker (*Picoides borealis*) habitat. The most numerous species in the diverse understory are pinehill bluestem, fringe nutrush (*Scleria ciliata* Michx.), grassleaf goldaster, pencilflower [*Stylosanthes biflora* (L.) BSP.], Texas dutchmanspipe (*Aristolochia reticulata* Nutt.), and bracken fern.

INDICATOR PLANTS

These monitoring efforts have led to interesting findings about herbaceous plant productivity and community health. Statistics from several sites that have been prescribed burned several times, but not within the last two growing seasons, are given in table 1. These results support several conclusions about herbaceous plant productivity: (1) herbage productivity in the pasture of native herbaceous vegetation is probably near the maximum for upland soils in central Louisiana without fertilization; (2) herbage yields decrease with increasing overstory basal

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Table 1—Selected stand information relating overstory and understory woody plant density to herbaceous plant productivity

Stand description	Overstory basal area	Understory (pine seedlings not counted)	Current-year herbage production
	<i>Ft²/acre</i>	<i>Stems/acre</i>	<i>Lbs/acre</i>
Native pasture	none	6,900 (2.3 ft tall) ^a	2,900
Shelterwood with reserves	35	9,900 (2.0 ft tall)	1,700
Longleaf forest	98	12,500 (0.5 ft tall)	1,500
Longleaf forest	106	65,200 (1.7 ft tall)	670

^a Average height of understory stems, excluding pines.

area; and (3) once a pine overstory has reached full stocking, efforts to increase understory herbage production by rotary mowing or burning will have marginal success. If hardwood brush or a midstory is present, herbaceous productivity will decline even further.

Since herbaceous plant productivity does not necessarily respond to management treatment, how we determine whether a treatment affects the health of a herbaceous plant community should not be based solely on its productivity. Rather, the focus should be on species richness and species distribution. To this end, indicator plants can be used as barometers of herbaceous community health. Based on our work, indicators of a healthy understory in upland longleaf pine landscapes might include pinehill bluestem, swamp sunflower, and grassleaf goldaster. Indicator plants would help forest managers quickly recognize sites needing treatment and or those sites where no treatment is required so that managers could best allocate their resources. With limited training, forest personnel can recognize many plants year-round in the field. The use of pictures and computer images could help with identification.

